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Ticket Validation in Public Transportation Using the Smartphone

João Pedro Santos Reis Leal

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Supervisor: Maria Teresa Galvão Dias

Co-Supervisor: Pedro Mauricío da Silva Moreira Costa

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Approved in oral examination by the committee:

Chair: Rosaldo José Fernandes Rossetti
External Examiner: Jorge Carlos dos Santos Cardoso
Supervisor: Maria Teresa Galvão Dias

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Abstract

The adoption of smartphones worldwide grows everyday and it is becoming a part of our everyday life, making it easier and always connected to the rest of the world. Furthermore, a bigger integration of this technology with mundane tasks is sought after. It is then in the context of this desire that this dissertation comes to light, by finding a way to integrate the smartphone with something that is a part of a significant number of people's daily commute: public transportation. Public transportation is an important part of our society, since many depend on it everyday, in order to fulfill their daily traveling needs, like going to work, going home, going shopping and meeting friends. With that in mind, it is clear the utmost importance of further improving this infrastructure, by allowing commuters to use their smartphone to perform tickets' validation.

This work provides a comparison and analysis of the use and costs of different technologies (NFC, QR Codes, Bluetooth and Location data), in the validation process of public transportation tickets. Aspects like the cost, device compatibility and ease of use are discussed and compared. After analyzing and comparing each technology, QR Codes and Location data were used to design three possible solutions to implement a mechanism that allows users to validate their tickets using their smartphone. With the chosen solution, an Android application and web server were implemented, which allows the validation of tickets. Other functionalities were implemented, in order to further approximate it to a production application, such as buying tickets and listing the past trips.

The created application was later on tested both in laboratory environment and in a real environment, with the company responsible for bus transportation in Porto's transportation system (STCP) and its respective customers. Two questionnaires were also sent to the experiment's participants, one before and one after, in order to determine the type of transportation users that were going to participate in the experiment and also gather feedback from them, about the created system.

As a result of this work, it was possible to produce a solution that would be interesting to implement in a real scenario. The application and the experiment done proved that is possible to implement a ticket validation solution using the smartphone, with the least possible cost while maintaining the reliability needed in such a system. It was also possible to conclude that there is a high interest from the users' side in the use of a such a system. Finally, the creation of a system that is easy to use for the users and that has low distribution and maintenance costs for the operators would be beneficial for both sides.

Resumo

A adoção de smartphones a nível mundial cresce diariamente e cada vez mais faz parte do nosso quotidiano, tornando-o mais fácil e sempre ligado ao resto do mundo. Para além disso, é procurada uma maior integração desta tecnologia com as atividades mundanas. É então no contexto deste desejo que esta dissertação surge, encontrando uma forma de integrar os smartphones com algo que faz parte da comuta diária de um número significativo de pessoas: os transportes públicos. Os transportes públicos são uma parte importante da nossa sociedade, já que muitos dependem deles todos os dias, por forma a realizar as suas necessidades de deslocação, como ir para o trabalho, ir para casa, ir às compras e encontrar com os amigos. Com isso em mente, fica clara a grande importância em melhorar esta infraestrutura, permitindo aos utilizadores que utilizem o seu smartphone para realizar a validação de bilhetes.

Este trabalho apresenta uma comparação e análise do uso e custos de diferentes tecnologias (NFC, códigos QR, Bluetooth e dados de localização), no processo de validação de bilhetes de transportes públicos. Questões como o custo, compatibilidade dos dispositivos e a facilidade de utilização, são aqui discutidas e comparadas. Após analisar e comparar cada tecnologia, os códigos QR e os dados de localização foram utilizados para desenhar três soluções alternativas de implementação de um mecanismo que permita aos utilizadores validar os seus bilhetes utilizando o smartphone. Com a solução selecionada, foram desenvolvidas uma aplicação Android e um servidor Web, que permitem a validação de bilhetes. Foram ainda implementadas outras funcionalidades, tais como a compra de bilhetes e a listagem de viagens anteriores, no sentido de aproximar a aplicação desenvolvida de uma versão de produção.

A aplicação criada foi mais tarde testada, tanto em ambiente de laboratório como em ambiente real, com a empresa responsável pelos autocarros no sistema de transportes do Porto (STCP) e respetivos clientes. Foram também enviados dois questionários para os participantes da experiência, um antes e outro depois, para que se pudesse determinar o tipo de utilizador de transportes que iria participar na experiência e também para recolher os seus pareceres acerca do sistema criado.

Como resultado deste trabalho, obteve-se uma solução que seria interessante de implementar num cenário real. A aplicação e a experiência realizadas provaram que é possível implementar uma solução de validação de bilhetes que utilize o smartphone, de baixo custo, mantendo a fiabilidade necessária num sistema desta natureza. Conclui-se ainda que há um grande interesse por parte dos potenciais utilizadores em utilizar este tipo de sistemas. Por fim, a criação um sistema de fácil utilização para os utilizadores e com baixos custos de distribuição e manutenção para os operadores, seria benéfica para ambas as partes.

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João Leal

"I'm a greater believer in luck,
and I find the harder I work the more I have of it."

Thomas Jefferson

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Abbreviations

QR Code	Quick Responde Code
GPS	Global Positioning System
NFC	Near Field Communication
OTA	Over-The-Air
RFID	Radio-Frequency Identification
BLE	Bluetooth Low Energy
REST	Representational State Transfer
API	Application Programming Interface
OS	Operating System

Chapter 1

Introduction

1.1 Context

Since the introduction of smartphones in the world, the way people live and work has been changing . This technology impacts “consumer’s behavior, marketing, business activities and education” [Ald12], and the growing adoption of this technology makes our lives easier and always connected to the rest of the world. Smartphones are making it possible to have a great amount of information readily available, everywhere we go. “The most significant feature of mobile technology is mobility: the ability to access services ubiquitously, on the move” [Nii06].

When witnessing this growing inclusion of the smartphone in people’s mundane activities, comes the need to adapt this technology for something that is a part of the daily commute of many: public transportation.

Public transportation exists in different shapes, involving different vehicles, tickets’ validation processes, fares, and, in some cities, different modes. Intermodal transportation allows people to use more than one means of transportation between their origin and final destination. For this to be possible, cooperation among transport operators and also a seamless means of ticket validation may be needed.

The adoption of mobile ticketing solutions in transports had a big evolution in the last years. The integration of mobile technology with public transports has many advantages, such as eliminating the need to go to a ticket machine to buy a ticket before entering a transport [Nii06], avoiding queues and always having information about travel history and available tickets.

This dissertation is integrated in the Seamless Mobility project, a project involving Octal-Novabase and FEUP. The general aim of the project is to develop, implement and test a prototype of a mobile ticketing framework in Porto. In this context, this dissertation aims to analyze different alternatives for the validation process, and covers areas such as mobile computing, ubiquitous computing and human-computer interaction.

1.2 Motivation and Goals

This dissertation comes to light in the context of the integration of mobile ticketing technology with public transportation. For this to be achieved, several components must be studied and implemented, for instance the tickets purchase process, the tickets validation process, the availability of schedules and routes and users' profile information. A virtual ticketing system has clear advantages in comparison to the traditional ones, since it allows the user to buy tickets anywhere, thus avoiding possible queues, and also ubiquitous access to personal information. In this study, the main focus will be the validation process, as it is one of the most challenging processes in the implementation of mobile ticketing [FDC14].

One of the goals of the project was to create an Android mobile application that allows users to validate tickets in the context of public transportation. This validation could be implemented using one or more of the following technologies: NFC, GPS and data networks (e.g. 3G, 4G), Bluetooth and QR Codes. Each technology was analyzed and compared in terms of cost, ease of use and reliability and, in the end, the ones that were considered to excel in most of these topics, were implemented. After the implementation, the resulting application was tested not only in laboratory environment, but also in a real environment, with a real company and its customers. The company selected to perform the tests is Sociedade de Transportes Colectivos do Porto (STCP), responsible for the buses in Porto's public transportation system. The real testing aimed to evaluate the application, in order to ascertain its ease of use and usefulness, as these factors are believed to be determinant for the general public's adoption of a new technology [Ald12]. It was also possible to determine possible further improvements, with the feedback received from the users.

The main goal of the project was to study the feasibility of implementing a ticket validation mechanism using mobile technologies, that brings the least possible deployment and maintenance costs to the transport operators, and to draw some conclusions about its practical use in a real environment.

To attain the proposed goals, the project was divided into two clear phases. Firstly, a research phase was conducted, in which a literature review of the existing systems that tackle this problem was done, followed by a thorough analysis of the four referred technologies, along with the definition of different use cases for each of the alternatives. Next, the technologies and respective use case that were found to bring the most advantages for both the users and the transport operators, were implemented through an Android application. This implementation was done using the agile Scrum methodology, with short sprints of around 2 weeks, that allow fast prototyping and testing of solutions. This way, by the end of the implementation phase, it was possible to have a testable prototype for the evaluation period that came afterwards. The last phase was the evaluation phase, in which the created prototype was tested both in laboratory environment and in a real environment, in parallel with Porto's current system.

1.3 Document Structure

Besides the current introduction chapter, this document contains 6 other chapters. Chapter 2 contains the state of the art of this problem and existing solutions to the problem are presented. In chapter 3, Porto's transportation system is presented, giving an overview of how it is currently implemented and its current issues. Chapter 4 makes a comparison of the technologies being studied, along with possible use cases. In chapter 5 the selected implementation case is described, and the resulting application is shown and explained. Chapter 6 is reserved for the presentation and description of the evaluation process, along with the results of the experiment. Chapter 7 is the final chapter of the document and exposes the conclusions and prospect of future work that can be done with the achieved results.

Chapter 2

Literature Review

There is a growing interest in integrating the smartphone in our everyday life activities. The focus of this dissertation is the use of mobile technologies as a virtual ticketing system in public transportation. There have been some previous projects that tried to achieve the same goals, some of them with success while others contributed to the advancement of the research field area.

The validation process using the smartphone can be performed using different technologies. There are multiple existing solutions that aim to achieve the best performance both for the users and the transport operators. In the following sections, some of these solutions are presented and discussed, according to the technologies used to implement the validation component. The final section presents the drawn conclusions and remarks, identifying where the solutions fail short and the points that this study should focus on.

2.1 Solutions based on NFC

NFC, or Near Field Communication, is a short distance wireless technology that allows consumers to exchange information with a smartcard or other NFC devices. This exchange can be made by bringing the NFC reader close to the passive tag (chip) or NFC device that contains the information being read, "at a distance that is less than 4 centimeters with a maximum communication speed of 424 kbps" [For15]. A smartcard is a card that contains a passive NFC chip that can be read by an active NFC device, which is called the reader in this case. A NFC tag is, for instance, a small sticker containing a NFC chip, having stored data in it, that can be read or written by an active device. Another type of passive component is a smartposter, which is a poster that contains a chip in it, allowing people to read the embedded chip.

We should also define the three modes that NFC in smartphones normally operates in. The first is reader/writer which is the mode in which the device acts as an active reader or writer. In the card emulation mode, the device acts as a card, allowing the reading of its contents by other active readers. This emulation can be done by means of a Secure Element, which is a physical chip located on the phone, or in the SIM card, that contains secure information and is not accessible by developers. Only phone manufacturers or network operators have the permission to write information, or applications, in the Secure Element (SE). Recently, it has become possible to do the card emulation mode using software, halting the need for the use of the SE. Finally, the third mode is the Peer-to-Peer mode, in which two NFC devices actively exchange information. In the Android case, the Android Beam protocol is used, allowing just one message at a time to be changed in each communication process.

Many solutions exist that use this technology to either do the purchase of electronic tickets, their validation or both. One of these examples is the implementation done by [BFFC13]. In their paper, the authors studied the concept of using an Android tablet as a ticket validator, being this a thin client, containing little to no validation logic, moving the business logic to a server in the cloud. The implementation was directed to Lisbon's subway system, and the implementation accounted for the use of the already implemented *Lisboa Viva* smartcards. The charging process and ticket validation process, in the gates, remains unaltered. The paper describes the implementation of a new ticket verification process, when the inspectors come to check the validity of users' tickets, using the aforementioned Android tablet device. Since the smartcards use RFID instead of NFC technology, it is not possible to read them using the Android device. To achieve that, an *AEP card reader*, that communicates with the tablet via Bluetooth, uses receiving commands from it and returns responses to it. On the other hand, the tablet communicates with the server, using the Internet, to do the validation of the ticket. In the paper, the authors point out some of the advantages of having most of the business logic in the cloud, like having a common logic, with easier maintenance, and also improved security of the process. Although the study discusses some interesting details about the validation process, it has the disadvantage of requiring the use of an external card reader and the fact that it does not use true electronic tickets, thus moving away from the scope of this research.

In the paper [WGSL12] a different approach to ticket inspection is done. In this case, the user buys the tickets over-the-air (OTA) and the bought tickets are stored in the device's secure element. Later on, when the inspectors appear to check if the user has a valid ticket, they do so by reading the user's secure element, using NFC, receiving the confirmation of whether there is indeed a valid ticket or not. The biggest disadvantage of this approach is the fact that the application has to be manually distributed, or has to come pre-installed on the device, since neither users nor developers can access the secure element. However, this paper brings an interesting concept, the blacklist concept, that allows blocking certain devices and users from using the transportation system, which might be useful, as referred in the paper, in case of theft of a mobile device to block that smartphone from being used.

A somewhat similar approach to the previous one can be found in [GSMM09]. In this study carried out in Rome, the application also has to be installed in the device's secure element. The concept of this research includes a fully implemented virtual ticketing mechanism, including the purchase, validation and verification processes. According to the research, each station is expected to have a smart poster that allows users to buy tickets when tapping their phone on it. Subsequently, users have to validate one of their available tickets in an appropriate NFC reading device, that validates the ticket. When an inspector appears, the verification is done using another NFC reading device (i.e. a smartphone), that reads the validated ticket stored in the secure element, and confirms its validity. Regardless of the secure element disadvantage, this paper takes some valuable conclusions in the field of virtual ticketing. The authors conclude that in such a system, what is important for the users is the efficiency, feeling of safety, ease of use and automation of all the process. Finally, some interesting observations were also taken, which is the case of the possibility of having more than one valid ticket at a time. This might be valuable for the implementation phase of the current research project.

There is also one paper that focuses its research on the problems that mobile ticketing using NFC might have [CMM+13]. On the one hand, the paper identifies possible disadvantages of using the secure element, such as the difficulty in accessing it and the need to tie transport companies to mobile phone manufacturers or network providers. Also, it identifies problems of using a virtual ticketing system. Some of these problems can be, for instance, the cloning of a ticket before it is validated, hence allowing multiple users to validate the same ticket, or cloning a ticket after it is validated, which allows multiple users to use the validated ticket during the valid time period. A third problem that is identified, is the man in the middle attack, that might occur when a third party hijacks the NFC communication, and uses that information for its own good. In this system, the validation of the ticket is done between the phone and a validator device (NFC reader device) and later, the ticket can be checked by the inspector using his own phone, by having the user's phone emitting an NFC signal to the inspector's phone. In this process, the validator is not connected to the internet, because otherwise it would require a major infrastructure hardware change, and it would be costly for the operator. Instead a security protocol was implemented. When a ticket is being validated, the user's device sends information to the validator, which in turn adds a token of its own to the message. When the message is received by the user's device, it is sent to the server, that processes it and validates the ticket. As such, the only communication with the server that is required is made using the user's device. For more information about the protocol, please refer to [CMM+13]. Finally, the authors suggest the use of biometric data, like a picture of the user, to ensure the authentication of the ticket to its rightful owner.

A different approach on the NFC use can be found in the [SGL13] paper. In this paper an inverse reader system is described. The system "consists of a mobile phone with NFC technology working in reader/writer mode, an NFC reader working in card emulation mode and a server infrastructure" [SGL13]. This translates to the use of an external device, the NFC reader working in card emulation mode, that communicates with the back-end server, to fulfill the validation process. On the other hand, the user has to open the application, select the ticket validation option and then bring the phone close to the validator, which, according to the authors, has the advantage of giving full awareness of the validation process to the user. Since the system was designed to be used in a gated system, the possibility for ticket inspections was not accounted for. This interesting approach shows us that it is possible to revert the roles in the system, opposing to the common case of having the phone working in card emulation mode, using the secure element.

A final and interesting approach that is discussed, differs from the previous analyzed papers in the fact that it uses offline ticket authentication, instead of the usual over-the-air process [WL13].

The authors point out the advantages of offline authentication, being them the speed of use and the user experience, that in applications like these are very important. But, facing the online authentication process, it lacks the security component which is of the utmost importance. The aim of the paper is then to solve this big disadvantage of offline authentication, and try achieving the best of both worlds. The process starts with the purchase of the tickets online, storing them in the secure element of the user's phone. To achieve the security in the authentication process, the ticket contains both a content part, with basic information about the ticket and readable by the user, and also an encrypted security part, using public key encryption. This security part is what makes the process safer, and it can only be decrypted by the reader. For this to work, the counterpart private key used for decryption, has to be previously installed in the reader's secure access module. This paper was quite useful to understand some of the security aspects of virtual ticketing, by providing a different approach in the ticket storage, in which each ticket has a public part, containing information available to the user, and a private part that contains security information for authentication, that cannot be read by the user. This approach has, once again, the disadvantage of using the secure element.

All the previous approaches cover different parts of virtual ticketing using NFC. We can observe that there are multiple ways of doing the validation process and that the security of the communication and the ticket information itself have to be taken into consideration. Most of the existing approaches use the card emulator mode, with resort to the secure element, which might not be the ideal mechanism, since the application distribution would be cumbersome. On the other hand, the card emulator mode using software has not been explored much, which might reveal to be one of the paths being followed along the project. Summing up, the analyzed mechanisms were inspiring and will be taken in consideration in order to achieve a secure and easy to use solution.

2.2 Solutions based on Location Data

Another possible way of implementing a virtual ticketing validation system is the use of location data, thus making this a location-aware system. Nowadays, smartphones have the possibility of determining their current position, using the Global Positioning System (GPS) and also the Network Location Provider, that uses Wi-Fi or cell tower signal to triangulate the device's current position [And15d]. The first method, GPS, is a satellite based navigation system that triangulates the current position of a device using a set of satellites for this effect. This method only works outdoors, and has a high accuracy, around 13m [HC08]. The second method uses the cell towers, or the router in case Wi-Fi is being used, to approximate the position by transmitting the mobile phone signal, and has less accuracy than the previous. It has though some advantages over the use of GPS, like the fact that it works indoors and also that it consumes less battery. It is possible to calculate the current location of the device using one or both. When both methods are used, a finer balance between battery use and accuracy can be achieved.

Some literature exists about the possibility of using location-aware applications to implement a virtual ticketing system or bus tracking system. Many bus tracking mechanisms, using GPS, exist nowadays and an example of this can be found in [SH14]. In this paper, the authors describe a system that tracks both the bus and the passenger positions in order to provide real-time information about the bus. With the proposed implementation, the user can find out the location and estimated time of arrival of a bus to the user's location, along with details like the reason for the delay. Even though the described system does not apply for the current research topic, it is useful to understand what is possible to do with location information of both the user and the vehicles.

In another inspiring paper, a system that uses GPS information to validate the ticket is also described [KV12]. This approach uses two of the technologies being studied in this thesis, QR Codes and GPS. When the user buys a travel ticket, the purchased ticket is sent to the user as a QR code and, when an inspector appears to check the ticket, he or she checks the validity of the ticket by scanning the QR code the user received, or by directly checking the tickets associated to the user in the inspector's application in case of battery failure, for instance. As for the use of GPS, it is used during the validation process of the ticket. The validation process described by the authors, consists of a location-aware process, that triggers the validation of the ticket when the user is in the expected location of departure. This paper revealed to be quite interesting for the current topic as it covers a possible representation for the tickets and also a way to validate tickets using location information, which might be one of the selected implementation choices during the implementation phase of this dissertation.

Another similar approach, that uses location information to validate public transportation tickets can be found in [BMSW05]. The system envisioned by the authors needs the users to check in and check out, thus marking their current position when entering and leaving a public transport, and it also needs the users' locations to be measured at defined time intervals during their trips. This allows the application to reconstruct each user's route, opening the possibility for an automatic pricing mechanism based on the calculated routes. This approach tackles the ticketing process in a different way since the ticket is not prepaid. Since the fare being charged to the user is based on the routes, it might be more useful for a postpaid system, that takes money from a user's account at the end of each month, according to the user's trips.

Lastly, a study closely related to this research topic was carried out in Porto, with the aim of creating a full ticketing system, involving the purchase and validation of tickets [FDC14]. In their study, the authors point out some disadvantages of using NFC, like the need for "service providers to invest in new POS and NFC-reading systems and enough number of customers with NFC-enabled phones and wanting to use them for payment purposes." [FDC14]. Having that in mind, the choice of implementing the virtual ticketing system was location data. In the proposed system the users are supposed to buy the tickets OTA beforehand and to validate the ticket the user has to select the station he or she is entering, the bus line being used and also the appropriate ticket type. In this case, location is used to reduce the number of options available for selection, in the case of the station selection, as it only shows the stations that are nearby. The research also includes a field experiment with real users, and one of the conclusions that was drawn from this study was the fact that having to make three selections to validate a ticket might not be convenient for the users, so this might be something worthwhile exploring in this dissertation.

The studied literature reveals that using location information in public transportation ticketing systems might be helpful. Some public transportation vehicles already have live location information being sent to the transport operators' servers, and interconnecting this information with the users' location might be a good path to follow in this research. Additionally, we can also deduce that using location information along with other technologies, like the already reviewed NFC, might reveal better solutions. Another important factor that shall be considered throughout this study is the usability of the produced system; it needs to facilitate the validation process as much as possible, for example by reducing the number of steps.

2.3 Solutions based on QR codes

QR Codes allow the storage of information in a 2D barcode format, storing information both horizontally and vertically, thus carrying several hundred times more information than regular barcodes [Wav15, FT11]. These codes can be read by dedicated readers, or using smartphones as long as they have a camera and autofocus feature [FT11]. Also, QR Codes have the advantage of being easily created and can be printed at a normal printer, thus making the process of physical distribution not expensive. Further exploring these possibilities, we can then adapt the use of QR Codes to the validation mechanism of a virtual ticketing system.

One paper proposes a virtual ticketing system that uses QR Codes in two different ways: as a station check-in, and corresponding check-out, and also as a ticket representation [FT11]. Beginning with the check-in/check-out component, for this part the authors decided to use either RFID tags or QR Codes. The choice to use both methods was due to the fact that, at the time of writing, the number of devices that had both a camera with autofocus and NFC capabilities was reduced, and, as such, both methods were implemented in order to allow more people to use the system. In this context, NFC and QR Codes work in a seamless way, since both have information stored that can be read using the corresponding method, NFC antenna or camera, and the processing of the information can be practically the same. With that in mind, in order to check-in or check-out the users simply have to read either the RFID tag or the QR code at the corresponding station, and the information is sent to the server for processing. As for the second use of the code in this system, a ticket representation as a QR Code, when a user buys a ticket, the issued ticket is sent to the user's device in the form of a QR Code. Upon the inspection process, the inspector has to read the issued ticket from the user's device using his smartphone and the server verifies the validity of the ticket.

The reviewed literature presents two possible approaches for the use of QR Codes in a virtual ticketing system. Similarly to the discussed paper, in section 2.2 we can find another system that uses QR Codes as a ticket representation [KV12]. Apart from the use of these codes as a digital ticket representation, from the reviewed papers, we can also conclude that QR Codes can be used as an alternative to NFC tags, since the idea behind both these technologies is to store information that is later on read and processed by a mobile device or a server. In the technology study and comparison phase, the ease of distribution and creation of these codes will be further explored, since it allows having a compact mechanism of ticket representation and inspection.

2.4 Solutions based on Bluetooth

Bluetooth is a wireless technology, that exchanges data over short distances using radio transmissions [SIG15b]. The most recent Bluetooth standard is called Bluetooth Smart, or Bluetooth Low Energy (BLE) and it has several advantages over the traditional standard, such as lower power consumption and enhanced range [SIG15c]. It is starting to be more adopted by the newest released smartphones, and in some cases it allows devices to act in peripheral mode, which is the case of Android's latest Operating System, Android Lollipop [And15a]. Another type of device that implements Bluetooth Smart technology is a Beacon. A beacon is a small device that periodically emits a Bluetooth signal, containing location information, that can be picked up by another device that is scanning for Bluetooth signals [SIG15a].

There is not much literature about using Bluetooth as a ticket validation method in public transportation, but there is one paper in which Bluetooth is used to detect end-to-end passenger trips on public transport buses [KCM10]. The authors suggest the use of an external Bluetooth scanner device, that periodically sends a discovery request and records the results of the responding Bluetooth devices that it found in the radius, which in this case represents the bus it is placed in. Crossing this information, with the location information obtained via GPS by the bus, it is possible to calculate the end-to-end trips of different passengers; in this case a passenger is a bluetooth device, the entity of that device's owner is not known. It is thus possible to recognize when a device enters and leaves the bus and, with appropriate data handling, calculate the route that each device made.

We can then conclude that Bluetooth might be a good option in implementing device recognition or to exchange information, similarly to NFC and QR Codes. With that in mind, Bluetooth can be further explored in order to implement a different validation process, which involves wireless exchange of information with the user device, by using a beacon for instance. This might further simplify the validation process, by removing the tag reading or QR Code scanning. Nevertheless, there is currently a master's thesis being developed in the Faculty of Engineering of the University of Porto, actively investigating this technology and the possibility of using it as a ticket validation mechanism in public transportation [Cou15]. This opens the possibility for future work, of comparing both solutions.

2.5 Conclusions

After reviewing some of the existent literature about the use of mobile technologies in the context of public transportation, we can understand that there are some approaches that handle the ticket validation and inspection processes. In the NFC case, most of the presented approaches either make use of the Secure Element that is inaccessible to developers, or require external NFC readers to implement the proposed solution, which would bring additional costs to this system. Though, there is one research opportunity that can be followed, which is the use of Host-based Card Emulation (HCE), which is now available in Android version 4.4 and up [And15c], that allows applications to act as a secure element, thus not requiring the existence of a physical secure element. NFC is the technology that has more research on its use to perform ticket validation and inspection processes.

As for the location-aware validation service, it also presents some window of opportunity by further exploring the integration of this technology with the other studied technologies here. In the presented approaches, one requires the user to check-in or check-out when they are leaving the transport, which could be further improved by not requiring the check-out step (or making it optional), thus adapting it better to Porto's transportation system reality, and the other requires the user to make three selection steps before validating the ticket, which might be cumbersome. So the best way to improve this, would be to either select a new method of cross-information with transports' location or by using this method along with other technologies.

The reviewed QR Codes solutions offered a good overview and ideas on how to use QR Codes in the ticket validation and inspection process. For the inspection process, the idea of having a QR Code as a ticket representation is a quite good one, so this will certainly be a solution being highly considered for a possible implementation of a complete virtual ticketing system. On the other hand, the validation process requires the user to scan the QR Code with the camera, which might have some disadvantages comparing with the use of NFC tags or Bluetooth beacons, as these two require less effort from the user. The advantages of using QR Codes might come from the fact that they do not have major additional costs associated with using them, since printing a QR Code is relatively cheap, thus making their distribution and maintenance easier and cheaper. Also, QR Codes have the advantage of having a higher compatibility rate with users' devices [FDC14].

Finally, the use of Bluetooth in this context has not been explored much, and there is a big window of opportunity to explore different uses of this technology in this context. One clear option for this implementation, might be the use of beacons, that can broadcast personalized information, but might have the disadvantage of having higher investment costs than other methods.

Summing up, a cooperation between technologies is predicted to be the implemented scenario in the end, since every technology has its advantages and disadvantages. As such, the idea is to possibly integrate different methods' advantages and come up with the solution that is least costly for the transport operators and at the same time easier to use, so that the adoption rate is as high as possible. In order to achieve this, a comparison between each technology and possible validation scenarios has to be done in order to better assess each technology costs and details.

Chapter 3

Ticket Validation in Public Transports

3.1 Porto's Approach

Porto has an intermodal public transportation system, composed of buses, trains and light rail, known as *Metro do Porto*. The transportation network is divided into zones, each one covering a certain area, in such a way that the prices of the tickets vary according to the number of zones the user is going to travel in. The minimum fare is Z2, which means that the ticket is valid for two zones. Also, after the initial validation, the ticket is valid for a certain period of time, and in this time, the user can use the same ticket to travel in the corresponding number of zones, counting from the departure station. In the case of Porto's bus system, according to *STCP's* last published Management and Sustainability Report [STC11], the system is composed of a fleet of 468 buses and 2651 stops. As for the light rail system, and according to *Metro do Porto's* 2013 Sustainability Report [dP13], the network is composed of 81 stations and 102 vehicles.

The infrastructure of Porto's system is open gated, meaning that users do not have to pass by a specific gate to get access neither to the bus nor the light rail. We can take Lisbon's subway system (*Metropolitano de Lisboa*) as an example of a gated system. In this system, to get access to the boarding area one has to pass a smartcard in a gate and if the card is successfully validated, the gates open and let the passenger access the boarding area of the station [dL15]. An image of the access gates is shown in figure 3.1.

Since Porto is based on an open gate system, the ticket validation process is different. In Porto, similarly to Lisbon, a smartcard (*Andante*), is used, which uses Radio-Frequency IDentification (RFID) and each card can only have one ticket type at a time, meaning that the traveler cannot have a smartcard containing Z2 and Z3 trips simultaneously, only multiple trips of a single type. In the case of the light rail, each station has free access and validation machines are available. Before starting the journey, the user must tap his pre-charged card on the reader, and after it is read and the information contained in the card is updated, it is valid for a certain period of time. During this period, the user can either use the bus or the *Metro*, but every time the user changes a vehicle, the

[1] Retrieved on January 2015, from the website: https://commons.wikimedia.org/wiki/File%3ALisbon_Metro_Gate_(3792223830).jpg

Figure 3.1: Lisbon Metro Gate [1]

smartcard should be validated again [dP15]. The next validations do not use another ticket until the time expires. Figure 3.2 shows an example of the validation machines used in Porto, and a validation in progress.

Figure 3.2: Andante Validation [2]

For the buses, the validation process is similar. Each bus has a validation machine and the user must validate his card once he enters the vehicle [SdTCdP15], thus making the validation process work in a seamless way between the light rail and the bus. If the user does not have a card or if it is not charged, a ticket can be bought to the driver using cash, serving this as the fallback alternative to the smartcard. There are different pieces of information that are important to be stored in the validation process, such as the time of the validation, the stop in which it was done and in the bus case, the line.

The inspection process of Porto's transportation system works by means of unexpected visits by the inspectors to the vehicles. The inspectors appear unannounced in a vehicle and check the

[2] Retrieved on February 2015, from the website: https://commons.wikimedia.org/wiki/File%3AValidar_Andante_(Porto).jpg

tickets of the people traveling in that same vehicle. If they find someone traveling without a valid ticket, that person is fined and has to abandon the vehicle.

3.2 Current Issues

Even though the current solution works, it is still possible to further improve it and adapt it to the use of smartphones, bringing advantages to the users and to the transport operators. The transition to mobile ticketing allows public transport operators to reduce infrastructure costs (as long as new hardware is not required) and also to collect more information about commuters' travel patterns, to further improve the service. Conversely, mobile ticketing has some advantages for the commuters over the current approach. These advantages are the possibility of users avoiding queues, which happens when users have to charge their smartcards or buy tickets on the bus, the reduction of the need to carry money to use public transportation and, finally, the use of the smartphone itself to perform this operation, which is something that a significant number of people carry everyday.

However, this transition to mobile ticketing is not an easy process since the implementation of an appropriate validation process is not straightforward. Most of the existing solutions, either require the user to fulfill a certain number of steps before the validation is completed (e.g. selecting the origin station, bus line), which might be cumbersome, or they require additional hardware that will bring a cost overhead to operators. There is also the case that some proposed solutions work in a close gated system, as opposed to the open gated system that Porto's transport infrastructure has, or they use methods that are not feasible nowadays, which is the case of the secure element.

As it was previously mentioned in the current document, ease of use is one of the most important factors in a new technology's adoption by the general public, and the implementation of this mobile ticketing service has to respect that principle. Another important aspect about the validation process being implemented is the fact that it has to be secure and reliable for both the user and the operator, since it contains money transactions (in a direct or indirect way) that cannot bring losses neither to the commuter nor the operator.

To sum up, the biggest challenge of implementing a validation mechanism in a mobile ticketing solution for public transportation is to find a mechanism that requires the least amount of steps possible for the users and also requires the least implementation and maintenance costs for the operators. A fine balance between ease of use for the commuters, minimum implementation costs for the operators while guaranteeing security and reliability for both customers and operators has to be found, in order to find a solution that satisfies both sides of this problem.

3.3 Integrating mobile technologies in the validation process

In order to come up with the best possible solution, all the technologies being studied in this project have to be analyzed and compared in terms of cost and ease of use. However, it is possible to have an outlook of what the solution will include and will possible include.

One of the identified challenges in implementing a validation mechanism in this context is the fact that it has to demand the least amount of steps being fulfilled by the user when validating a ticket. Usually the number of steps required comes from the fact that the origin or destination station have to be selected, as well as the indication of the ticket type being used and also the line associated with the transport. The proposed solution aims to reduce these selection steps. Next, the different reduction possibilities are as follows:

- **Line selection:** A possible way to remove the line selection, is by using an identification mechanism in the vehicle being boarded or in the station the user is going to board the vehicle. That can be achieved for example by using QR Codes, NFC tags, Bluetooth beacons or by integrating and processing the location information of the vehicle and the user's device. Any of these technologies allow us to automatically identify the vehicle the user is boarding and consequently the identification of the line, thus cutting down one step in the validation process.

- **Boarding station:** In order to eliminate the need to select the origin station, we can use the location mechanisms used for the aforementioned line selection, or by placing a QR Code, NFC tag or Bluetooth beacon in the origin station containing information about the station at hand, and possibly about the intended line being boarded. For the first use case, if the vehicle the user intends to use is identified by the device, using any of the already described methods, it is possible to know where that vehicle is located at that moment and consequently where the user is. For the case in which stations would contain codes, the user would check-in (read a code) when at the station and the device would store the information of where the user intends to start the trip. After that, before or at the moment the intended vehicle arrives, the user can select the ticket type being used, and the origin station that would be used would be the one previously scanned by the device, thus cutting down the step of having to manually select the origin station.

- **Ticket type:** The ticket type selection has to be selected at all times by the user. Nonetheless, there is a way to reduce this step in most of the validations, for example by allowing the user to configure the default ticket type being used during every validation.

Combined, the proposed options have the possibility of reducing the number of steps of performing the validation to one, which would be to scan a QR Code, NFC tag or Bluetooth beacon signal. This way, we can emulate the number of steps required in the traditional approach. To decide on the final implemented solution, the costs of each of them have to be analyzed and further details about each technology have to be researched.

Chapter 4

Designing a mobile ticketing validation solution

The current chapter presents and discusses different alternatives for the mobile ticketing validation process and discusses the advantages and disadvantages of the corresponding technologies. Chapter 2 has already presented the technical details of each technology, so to find out more about these details, please refer to chapter 2. Since the main focus of this chapter is the propose different solutions for the implementation phase, the first section is dedicated to the comparison of each technology's advantages, disadvantages and costs. The second section presents possible use cases of the studied technologies, thus proposing various possible solutions that might be implemented during the implementation phase. Finally, the last section presents the conclusions drawn from the analysis, and the best solution for implementation is chosen.

4.1 Comparison

All the technologies that were studied can be used to locate a device, and can be called micro-location services [Loc15]. Furthermore, NFC, QR Codes and Bluetooth can be used to perform simple unidirectional information exchange, allowing user's smartphones to read or receive small pieces of information that might be processed in order to perform certain actions.

Location data can be obtained by using the GPS antenna available in most existing smartphones or by data networks, that triangulate the user's location based on cell towers' locations. Alternatively, Wi-Fi can also be used, but the router is used to calculate the user location instead of cell towers. These last two methods are used in the Network Location Provider available in Android devices. Two of the biggest advantages of location data is the fact that it does not incur any costs neither to the users nor to the transport operators, and also the fact that most existing smartphones have compatibility with it. However, when using data networks, instead of Wi-Fi, the mobile devices' owners need to have a mobile plan that allows them to use a certain amount of data free of charge, otherwise they will have to pay for the amount of data that was used. Another advantage is the fact that it does not require any action from the smartphone owner in order to determine its location.

On the other hand, this technology has the disadvantage of not providing a completely accurate location to the user's device. However, by using GPS instead of the Network Location Provider, it is possible to achieve more accurate results. When using GPS to calculate the location, it consumes more battery power, making it inconvenient for the user when used for long periods of time. Finally, GPS only works outdoors which might be not ideal in situations where a transport station is located underground or inside a building. To overcome the last two disadvantages, it is possible to combine the use of GPS with the Network Location Provider [And15d], since the latter works indoors as well, hence being able to achieve location data both indoors and outdoors as accurately as possible, at a lower battery consumption.

From the existing literature and the details about location data, we can understand that this technology alone is not ideal to be implemented in such as system, since the mobile ticketing system needs more accurate information about the user location and possibly information about the line the user is going to use. As such, in order to achieve better results, one or more of the remaining technologies might have to be used along with it. Table 4.1 summarizes the different location possibilities, and its respective advantages and disadvantages

Table 4.1: Location Data Summary

Technology	**Advantages**	**Disadvantages**
GPS	• High accuracy • No costs	• Higher battery consumption • Does not work indoors
Network Location Provider	• Works everywhere • Lower battery consumption	• Lower accuracy

Near Field Communication, or NFC, is a technology that allows devices to receive information from a small chip. The cost of this technology is not particularly high per piece, but it is the second highest cost technology presented here. If bought in bulk, it can reach prices of around 0.1 €, per NFC tag [Loc15]. Depending on the store, if the quantity of NFC tags that is bought is reduced, the price per unit can reach prices of 0.5 € [Rap15]. NFC has some advantages like the ease of reading a tag for the user, since the user simply needs to unlock the phone and tap it on the intended tag, and the possibility of visually customizing the tags. It has though the disadvantages of being a technology that is not available in every smartphone and not very well known by the general public.

Similarly to NFC, Quick Response (QR) Codes is also a technology that is mostly used to read a small bit of information from a code. If the code stores information about the current station, and also about the line the user wants to use, the system can determine the user's current station, and possibly, the bus line he or she intends to travel, for further processing. Excluding location data, QR Codes are the cheapest technology presented here since the only cost associated with it is the cost of printing something. So, having in mind our study case of public transportation systems, we can print one QR Code along with the sheet of paper of a bus line schedule, which makes the cost of deploying a QR Code equal to the price of printing a sheet of paper. To make the deployment cheaper, transport operators can print multiple QR Codes in a single sheet of paper, which makes it even cheaper. Taking as example the price of printing a black and white page in the Faculty of Engineering of the University of Porto [FEU15], we can assume a maximum price of 0.03 € per QR Code. If a colored page is printed, we can assume a maximum price of 0.14 € per QR Code.

QR Codes also have the advantage of being supported by all the smartphones [Uni15], since only a camera with autofocus is required and QR Codes are already known and accepted by the general public, since they are used in many places (e.g. magazines, advertising). One of its disadvantages is the fact that the reading process might be slower than NFC tags, since apart from unlocking the phone, the user also has to open the application and point the camera to the code. Also, the level of customization of the codes' look is more reduced than NFC tags.

Finally, Bluetooth is a wireless technology that is nowadays available in most smartphones. The most recent standard is Bluetooth Smart, or Low Energy, and it is a Bluetooth version that consumes less battery power. There are also some Bluetooth devices, called Beacons, that emit a Bluetooth signal that can be received and processed by receiving devices, such as a smartphone. Beacons are more expensive than the previously presented technologies, having an average cost of around 30 € [Gim15, Est15], per unit. There is a low cost option, with a price of around 5 € [Gim15]. Beacons have the advantage of not requiring the user to interact with the smartphone in order to receive the signal being emitted, and also the fact that the signal can be received at longer distances than NFC and QR Codes. The biggest disadvantage is the fact that beacons need to have a power source, so in case a battery is being used to power the beacon, it might need to be replaced or charged periodically, which brings additional costs to the transport operators. For the purpose of this analysis, we can consider that beacons would be placed in the vehicles or in the stations.

Table 4.2: Technologies' Comparison Summary

Technology	**Price (€) / unit**	**Advantages**	**Disadvantages**
Location Data	0 €	• High availability • No interaction needed	• Not fully accurate • Battery consumption
QR Codes	0.03 €	• High availability • High acceptance	• Higher user interaction • Lower customization
NFC	0.5 €	• Visual customization • Low user interaction	• Lower availability • Not well-known
Bluetooth	30 €	• Long distance reception • No interaction needed	• Power source needed • High cost

Table 4.2 summarizes each technology cost for the operator, advantages and disadvantages in order to allow a more direct comparison. The prices presented in the table assume that individual units are bought, instead of being bought or printed (in the case of QR Codes) in bulk. As

aforementioned in the current document, the main focus of this dissertation is to find an effective and efficient validation mechanism with the least implementation and maintenance costs possible. To achieve this, one or more of these technologies can be used, guaranteeing low costs for the operators and high acceptance by the general public, after a possible deployment.

With that in mind, and knowing that location data alone is not enough to design a mechanism that is easy to use, since both the boarding station and transport line being used by the user should be identified by the system, as referred in section 3.3, we have to choose one of the other three technologies in order to be able to more easily and surely identify these two aspects. The high price per unit of Bluetooth justifies its exclusion from our proposed solution. So the choice falls between NFC and QR Codes, being both technologies analogue to each other, since both of them consist of storing data that is read by a smartphone. QR Codes was the selected technology due to its low cost and ease of replacement, since different replacement codes can be printed at a very low cost, and can be easily replaced, for instance, by gluing the new code on top of a damaged one. Furthermore, QR Codes have bigger compatibility with the existing devices than NFC, which is a big advantage in case a larger number of users is intended to be achieved. On the other hand, even though NFC requires less interaction from the user, it has a slightly higher cost than QR Codes.

Let's now assume a possible case in which a hypothetical amount of 500 codes (or tags) needs to be deployed in a public transportation network. As an example, we assume that for bulks of 500 units we can buy NFC tags for 0.1 €, which makes a total cost of 50 € for 500 tags. While on the other hand, assuming for example that we can print 10 tags in a sheet of paper, if 500 codes are needed, we need to print 50 pages at a cost of 0.03 € each, which gives us a total of 1.5 €. As we can see, when we scale out a solution that uses NFC tags, we obtain a higher cost than when QR Codes are used.

Summing up, Location Data and QR Codes are clearly technologies that allow the implementation of a validation mechanism with reduced costs. Bluetooth will not be considered in the proposed solutions, due to its high cost. NFC will not be directly specified in the proposed solutions, since it works similarly to QR Codes, but if there is enough investment money to implement a solution that uses NFC, it can be done so by using NFC tags in the place of QR Codes. With the use of NFC, a solution that is easier to use for the users can be created, since it requires less interaction, at the expense of a slightly higher investment and maintenance cost.

4.2 Possible Solutions

Having compared the technologies, we can now present possible validation mechanisms. Different solutions with different validation flows for the users are proposed, and they can either use QR Codes or NFC. The solutions are described using QR Codes, to simplify the description process, but, in case NFC is used, QR Codes simply have to be replaced by NFC tags. Furthermore, the presented solutions allow the system to know the line that the user wants to use and also the station where the user is when boarding the vehicle. All solutions have a mandatory check-in step, which is the validation itself, and an optional check-out step, that only happens for some configurations of the system.

Firstly, it is convenient to describe the general component of each proposal. The implemented solution should be flexible so that it can be adapted to different uses of the developed system. As such the system must allow the user to select the ticket type to use (in the case of Porto's network we have the different Z ticket types) or let the system automatically calculate the fare that will be charged to the user, based on the check-in and check-out locations. This last scenario is one in which check-out might possibly be mandatory. The presented solutions propose a configuration option that allows users to select three different possibilities:

- **manual ticket type selection**, requiring the user to select the ticket type everytime a validation is being performed;
- **pre-configured ticket type**, in which the user previously configures the ticket type that will be automatically selected when a validation is performed, similarly to Porto's current system in which an *Andante* only allows the user to charge and use a certain ticket type (e.g. Z2);
- **automatic ticket type**, in which apart from checking-in which is common to every configuration, the user is also required to check-out and the fare is calculated from the route of the trip that was done, using the entry and exit stops and the line that was used.

In this last configuration, in case the user does not check-out, the maximum possible fare is charged. Also, the system will have as its initial configuration the manual type. Finally, for both solutions the system will use location data to ensure that the information read from the code was read in the expected location. This way, some fraudulent actions can be avoided, such as when someone copies a code and uses that code to validate a ticket in a different physical location than the code is expected to be.

4.2.1 Solution 1 - QR Codes in stations

The first solution assumes that various QR Codes are placed in each station or stop, one per each line that passes through that station. For the purpose of this solution, the description focuses on the case of a bus system, in which it is assumed that an average of 3 lines passes in each station. As such, each station would have on average 3 QR Codes printed and placed on it, each code identifying the station and the line.

The idea behind the first solution is to allow the user to scan the appropriate code after arriving at the station, based on [GSMM09, BMSW05]. The system would then know the departure station and the line being used by the commuter. The validation should not be performed right away, in case the user changes his or hers mind and decides to board another bus or not travel at all. In order to give this option to the user, the system requires another step from the user: pressing a validation button on the screen, to confirm the validation. Having this functionality in the system, might bring additional problems to the solution, since if the time to press the validation was not restricted, the user could travel without ever pressing the button. Consequently, the time to fulfill this validation step is limited, allowing the user to perform the validation only during a particular time frame (e.g. 5 minutes). After this time has passed, the user is required to read a code again. If a code is read during that time frame, the previous validation option is replaced with the new line, station and time limit information. This also has the advantage of allowing the user to only validate the ticket when the intended transport arrives.

The check-out step is optional, and it depends on the transport operator configuration of the system and also on the user ticket type option (if automatic is chosen, check-out is mandatory). In this solution the check-out step can be done by reading a tag in the destination station. Moreover, if the user uses different lines, or different transportation modes, some transport operators might want the commuter to revalidate his or hers ticket every time a new vehicle is boarded. That can be done by selecting the appropriate revalidation option in the application and then reading a code in the intermediate station.

To provide more comfort to the user, a configuration option can also be added to the application in order to allow the user to choose whether the validation is to be done automatically after a code is read or to have the option of having the aforementioned time frame option, that allows the user to validate the ticket during a certain period of time after a code is read.

The state diagram in figure 4.1 depicts the described process in a visual way, so that all the possible states of the system can be further analysed along with their transitions and respective actions that cause them.

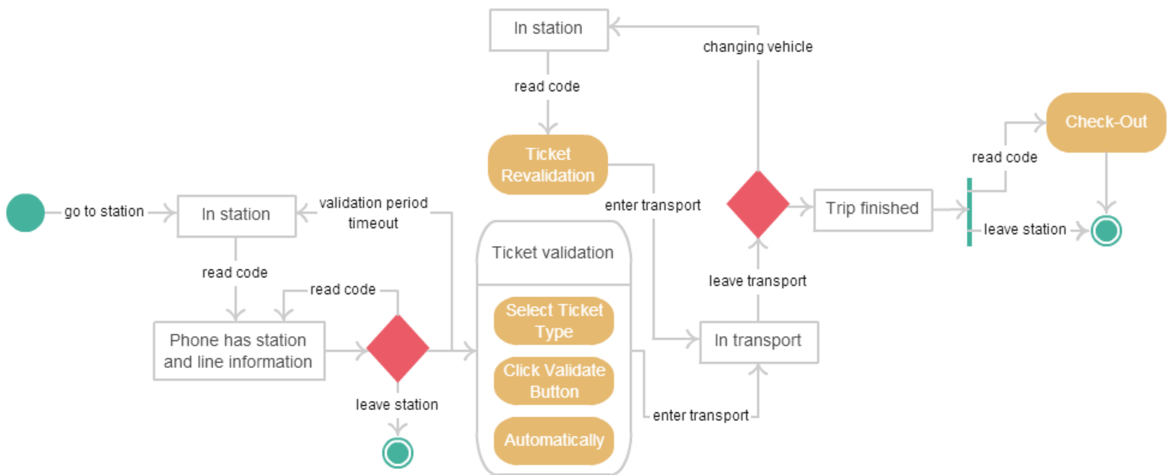

Figure 4.1: State diagram of the first solution (codes in stations)

4.2.2 Solution 2 - QR Codes inside the vehicles

The second solution tackles the reading process in a different way, emulating the validation process of the Andante in Porto's buses [SdTCdP15]. In this case, the codes (or tags for that matter) will be placed inside the vehicles, requiring the reading process to happen inside the transport. So, using the bus case again as an example, each bus could have a certain number of codes (for example, 3 codes) placed inside it and the user would simply be required to read one of these in order to perform the validation step. We will assume that 3 codes are placed inside each vehicle, so that more than one person can perform the check-in step at the same time. In this case, the time frame option presented in the previous solution would not be possible, since the validation of the ticket has to be ideally done as soon as the bus is boarded. Nevertheless, the ticket type configuration option is still valid and in case the manual ticket type option is active, the validation would only be completed once the user selected the ticket type being used for that trip. As for the revalidation process, that would be done simply by using the revalidation option in the application and reading a code in the new vehicle being used.

In similar fashion to the previous solution, check-out would be optional or mandatory in case the automatic ticket type option is active. This would be done by cross-validating the location data of the user device, and in case it is possible, with the location data from the vehicle itself. In case the solution is indeed adopted by one or more transport operators in Porto, or possibly by other operators, they can decide whether to include this cross-validation of the location data or not. In case the location data of the vehicle is not used, the location data of the user's device alone will be used, although it does not ensure full reliability of the data. Summing up, to perform the check-out, when leaving the vehicle, or right before he or she leaves, the user simply has to click a check-out option on the application screen, and the system will perform the check-out using the information of the line that is being used and the location in which the user is leaving the vehicle, thus calculating the final station where the user left.

Similarly to the previous solution, the state diagram presented in 4.2 shows a visual representation of the described solution.

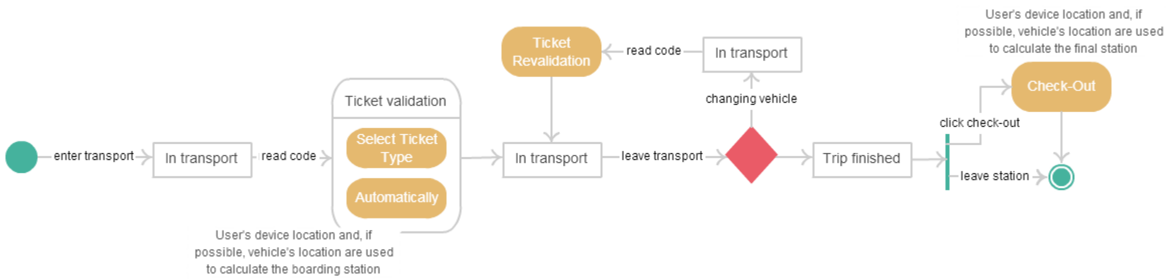

Figure 4.2: State diagram of the second solution (codes in vehicles)

4.2.3 Solution 3 - QR Codes in stations and in vehicles

The final solution presented here, uses concepts of both the solutions presented before. In it, the user is supposed to validate and revalidate its ticket after boarding the bus, but the check-out process differs. Instead of fully relying on the user's device's and vehicle's location data, a QR

Code (or NFC tag) is placed in each station with the special purpose of allowing users to check-out of a trip, making a total of 3 codes inside the vehicles and 1 in each station. As such, the flow of this mechanism would require the user to check-in after boarding the vehicle by reading a code inside the vehicle and in the cases where check-out is required, that would have to be done by reading a QR Code on the destination station. Similarly to the previous solutions, location data can be used to ensure that the user is reading a specific code by verifying if the current user location is the same as the code is expected to be. The QR Code placed in the stations allows the application to determine the correct check-out station, by reading the id contained in the code, and the system can verify if the user's location is in the surroundings of that station, hence making the check-out step more reliable.

Figure 4.3 shows the state diagram of this solution.

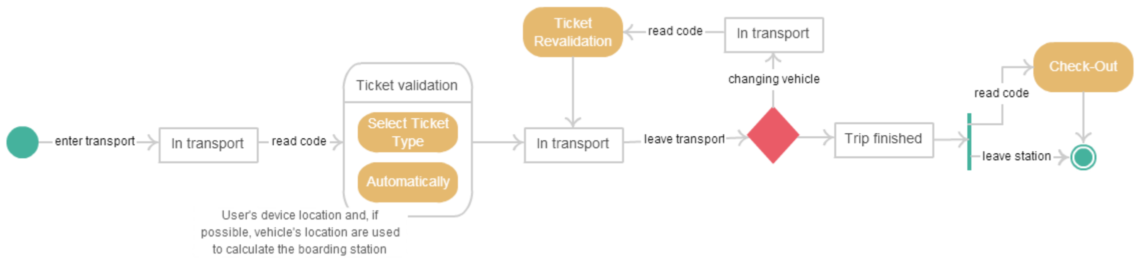

Figure 4.3: State diagram of the third solution (codes in vehicles and in stations)

4.3 Conclusion

The proposed solutions use different quantities of codes or tags, and as such they have different costs for the operators. The first solution assumes that an average of 3 codes are deployed in each station, the second assumes an average of 3 codes deployed inside each vehicle, and finally the third solution assumes an average of 3 codes inside each vehicle and 1 in each station. Using the statistics that were presented earlier on in the document about the number of vehicles and stations in Porto's bus network system, we know the total value of each: 2651 bus stops and 468 vehicles. The following list shows the average number of codes required for each solution:

1. 3 x 2651 = 7953 codes/tags
2. 3 x 468 = 1404 codes/tags
3. 3 x 468 + 1 x 2651 = 4055 codes/tags

To calculate the deployment costs of each solution, the prices that were used as an example in section 4.1 will be used. The only maintenance costs associated with the proposed solutions is the replacement of damaged codes, since the codes only contain the identification codes of vehicles and stations, which should not change, thus making the codes information independent of schedule and line changes. So in this case, to print 10 QR Codes we will assume an average price of 0.03 € for printing a sheet of paper, which makes up a total of 0.003 € per code. As for the NFC tag, we assume that the tags will be bought in bulk and for an amount of over 500 tags, each will cost 0.1 €.

Table 4.3 shows the total price of deploying these solutions, using either NFC or QR Codes, in the case of Porto's bus network.

Table 4.3: Proposed solutions' cost

Solution	**QR Codes Costs (€)**	**NFC Costs (€)**
Solution 1	7953 x 0.003 € = 23.86 €	7953 x 0.1 € = 795.3 €
Solution 2	1404 x 0.003 € = 4.21 €	1404 x 0.1 € = 140.4 €
Solution 3	4055 x 0.003 € = 12.17 €	4055 x 0.1 € = 405.5 €

It can be seen in table 4.3 that solution 2 is clearly the cheapest solution, when compared to the other two. If cost is the only factor that weighs in the final decision, the second would be the winner solution. But since the ease of use and other system requirements, such as information maintenance, have to be accounted for, we have to analyze these aspects on each solution. Firstly we should compare the first solution with the remaining two, since the latter are very similar. The first solution requires the user to read the code when in the station. Even though this gives the user more control, since the user directly chooses the line he or she is going to use, in some cases it can be inconvenient. An example of such a case is when a commuter is in a hurry to board the vehicle. In this situation, the second and third solutions would allow the user to validate the ticket inside the vehicle, after successfully boarding it, thus not requiring the user to stop and read a code in the station. Furthermore, the second and third solutions do not have the additional validation step, in which the user is required to press a validation button in the application, hence reducing one step in the whole process. Also, these two solutions have the advantage of having lower investment and maintenance costs.

Comparing the second and third solutions, we can see that both have different advantages over the other. The second has the advantage of not requiring the user to read another code in the cases that check-out is required, but facing the other it has the disadvantage of having the check-out process more prone to be cheated, since it depends solely on location information.

We can then conclude that solutions 2 and 3, are better than solution 1 both regarding costs and ease of use. The choice between these solutions will depend on whether the cost difference is significant or not for the operator and also the number of check-outs that are expected to be done on the system. For the purpose of this dissertation, the solution that will be implemented will be the third one, depicted in figure 4.4. This choice falls on the fact that this way a more robust check-out step can be implemented, and also it does not make the developed system too tightly coupled with information that comes from the operators. The codes that will be used for the check-out step will contain the information about the station, thus not requiring the location data of the operator to be used. Finally, for research purposes, this solution will be implemented using both QR Codes and NFC tags, so that both technologies can be used during the testing phase.

Figure 4.4: Representation of the selected solution [3] [4] [5] [6] [7]

[3]Retrieved on March 2015, from the website: http://blogs.office.com/2014/01/27/skydrive-and-skydrive-pro-are-now-onedrive-and-onedrive-for-business

[4]Retrieved on March 2015, from the website: http://smartcompanion.projects.fraunhofer.pt/

[5]Retrieved on March 2015, from the website: http://ipsisnet.blogspot.pt/2012/12/metro-do-porto-pretende-reduzir-50-dos.html

[6]Retrieved on March 2015, from the website: http://commons.wikimedia.org/wiki/File:Esta%C3%A7%C3%A3o_Baguim.jpg

[7]Retrieved on March 2015, from the website: http://NFCtags.com

Chapter 5

Prototype implementation

After designing a mobile ticketing validation solution, a prototype with the purpose of studying the feasibility of that solution was developed. The prototype implements the solution selected in chapter 4, implementing all the necessary functionalities to make the system work in a real scenario. In order to achieve these functionalities, both a server and a mobile application were implemented.

This section presents the prototype itself, including the architecture of the system as a whole, the technologies used in both components of the system, the underlying data model and the main functionalities of the system. Furthermore, an overview on how the prototype application is supposed to work is also shown, so that deeper details of the prototype can be conveyed.

5.1 Architecture

The developed prototype follows a general client-server architecture, in which a server processes requests coming from different clients, being a client represented by a mobile device. The server itself can be deployed in two ways: either as an internal service of the existing operators' servers, or as an external server that accesses the existing servers. The latter would add another layer to the system, thus requiring the new server to send requests to the existing servers to perform any necessary fetching or processing of information. In the scope of this project, an internal server was assumed to be developed, thus being a system with an internal server that contains all the operator's information and does not make use of additional servers. Additionally, the system also needs a database to persistently store the data. In the prototype implementation this was done using an external database service, hence adding another layer to the system.

Apart from these components, the system will also contain passive components which are the codes that are placed inside the vehicles and in the stations as well. These codes follow a defined format, explained in section 5.3, that was designed in order to reduce the amount of information stored to a minimum.

The diagram in figure 5.1 presents the architecture of the system, including the case in which an additional server is used.

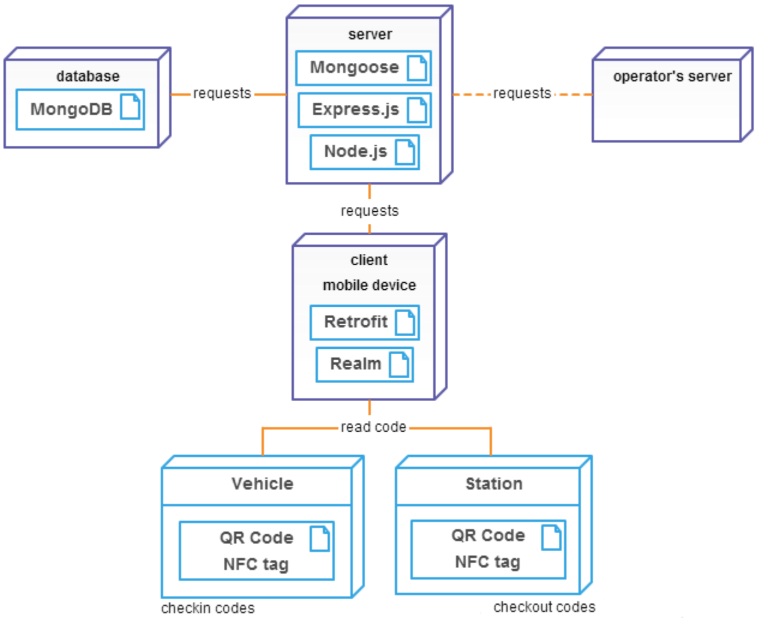

Figure 5.1: Architecture of the system

5.2 Server

As described earlier, the server is the component which handles all the requests coming from the various mobile clients and it was deployed in public domain, so that it can be accessed ubiquitously. This server provides a public REST API that handles different requests and takes care of fetching and updating the information in the database, which makes it fundamental to the system, since the mobile application cannot work properly without it. This server was developed in cooperation with another master's thesis, that is working on a similar concept of implementing ticket validation in public transportation, solely using BLE and Beacons [Cou15].

Representational State Transfer (REST) APIs allow the development of web services, where "the separation of concern is clear" [AN11]. It makes the development of web services easier, by making every resource accessible using the same protocol, which is HTTP, by creating unique URLs to access each resource [AN11], using different HTTP methods (e.g. GET, POST, PUT, DELETE).

The existence of this server is what allows the operators to gather information about the users' trips, and other types of valuable information, and also for the users to access updated information anywhere, as long as there is an Internet connection.

5.2.1 Technologies

In order to implement the server, different technologies were used, that allowed fast prototyping and continuous evolution of the solution. The most important technologies are now presented, exposing some details about them and the reason of choice.

- ***MEAN.JS***: *MEAN.JS* is a full-stack JavaScript solution that helps in the development of fast web applications [MEA15]. *MEAN.JS* is not a technology itself, it is though composed of 4 different technologies, offering a skeleton for a full-stack web application, that allows the development of either the server side, the client side or both. The provided skeleton is a MEAN application, and this is an acronym for the technologies that it uses, which are: *MongoDB*, *Express*, *AngularJS* and *Node.js*. In the scope of this project, since a web client was not needed, only the server side part was utilized, hence leaving AngularJS out of the list of technologies being used, making it a MEN stack. Next, these technologies are briefly presented, with the exception of AngularJS that was not used.

  - ***MongoDB***: *MongoDB* is a *NoSQL* database solution that allows the development of performant and scalable applications, with agile use of databases [Mon15a]. NoSQL databases are made for scalability and allow systems to handle large volumes of structured and unstructured data [Mon15c]. Additionally, agility in this context means the ability to adapt to change in an easy manner throughout the course of a system's development. The biggest benefit of using *MongoDB* in this context, is the ability to store any data structures and to develop flexible data models that can be easily modified, thus supporting the evolution of the prototype's underlying data structure.

  - ***Node.js***: *Node.js* is a platform for building fast and scalable network applications, which is lightweight and can be used in data-intensive applications [Nod15]. Besides being already bundled with *MEAN.JS*, the main benefit that this technology provides for the purpose of this project, is the speed and flexibility at which web servers can be built.

  - ***Express***: In order to make *Node.js* easier to use, *Express* was created to serve as a framework that, among other things, provides several HTTP utility methods, which allow the creation of robust APIs quickly and easily [Exp15], which is advantagous to the development of the prototype.

  Summing up, the main benefit of using this MEN stack solution, is the fact that it allows fast prototyping of a web server, using a single underlying technology, JavaScript.

- **MongoLab:** The database was deployed in a free external service that allowed the hosting of *MongoDB* solutions. In order to achieve that, *MongoLab*[Mon15b] was used due to the ease of use and the amount of free database capacity made available.

- **Heroku:** Similarly to the database, the server was also deployed in a free hosting service. *Heroku* was used to do that, due to the ease of the deployment process and also the possibility of having one deployed application for free.

5.2.2 Data Model

A complex data model for the system was designed, containing different entities. The main domain that we find in these entities, is the public transportation domain as it would be expected, since most of the models are related to components of a transportation system.

The most important model of the system is the Checkpoint model, which represents a reading of a code by a user, storing the location where it was read, the date of reading and also the station associated with that reading. Furthermore, there is a model that represents a trip of a user. Apart from the creation date, it stores information of the type of trip being done, storing whether a check-out is required or not and, in the cases it is not, it stores a validated ticket.

There are also models that store information about the transportation infrastructure, like the existing stations, lines and vehicles. Finally, there is also the user model, which stores basic information about the user.

Figure 5.2 shows a diagram representation of the data model of the developed system.

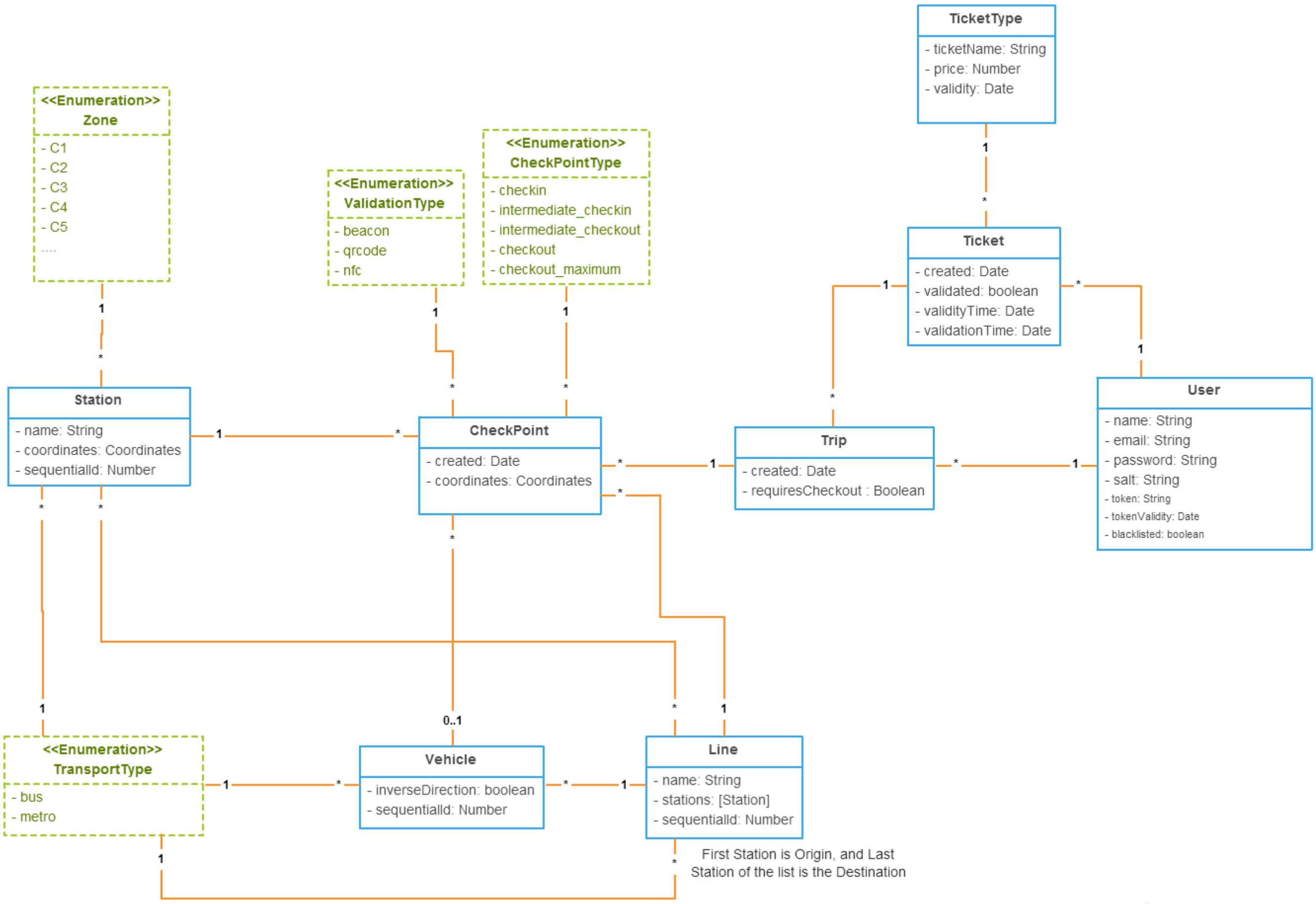

Figure 5.2: Data Model of the system

5.2.3 API

The server offers a public REST API, which makes available several methods that can be used to develop clients that use the API. The mobile application prototype is an example of such a client, that uses some of the functionalities available. In this section, the most important API calls will be presented.

It is important to describe some general aspects about the API itself. Most calls require the request body to be sent along with the user's id and also its token, so that the requests can be validated. Lastly, the server does not implement any major security measures, since the focus of the prototype is to test the feasibility of a validation system using the selected technologies, and not the technical implementation details of such a solution.

The API calls that will be presented play an important role in the well-functioning of the system, and as such, some details about each of them will be given. Apart from the /login method, all the other methods that will be presented require the user's id and token to be sent along with the request's body, meaning that authenticated requests need to be sent as a POST request.

- **POST /login:** This is the method that allows users to authenticate themselves in the system and, in order to do so, users have to send an email address and a password. If the user does not have an account in the system, one is automatically created when the first login request is sent. After processing the request, the server responds with the newly created token, token validity and user id.

- **POST /trips:** One of the most important parts of the system, is the ability for the user to find out his or hers trips. This method is used to fetch either every trip, the currently active trips or the past trips. It allows a filter parameter to be sent, called *filter*, that can take on the values *active* or *inactive*, so that the currently active trips or the past ones can be fetched, respectively. An active trip is one in which the validity time has not expired yet. If a ticket is used, the validity time is the validity time of the ticket, otherwise it is the longest validity time of the ticket types.

- **POST /tickets/list:** This method allows the tickets belonging to the requesting user to be fetched. Similarly to the previous method, *valid* or *invalid* tickets can be filtered out by means of a *filter* parameter. Valid tickets are the ones that have not been validated yet, while invalid tickets are the ones that the validity time has expired or where already validated.

- **POST /checkpoints:** This is the most complex method of the system, since it is used to perform either a *check-in*, an *intermediate check-in* or a *check-out*. The body of the requests has some mandatory elements to be sent, and they are the type of the checkpoint (*checkin*, *intermediate checkin* or *checkout*), the coordinates from where the request was done, containing the latitude and the longitude, a timestamp to allow checkpoints that were read offline to be synchronized with the server and the validation type (NFC or QR Code). The are also other parameters that are used specifically for each checkpoint type. For the *check-in*, the ticket type being used shall also be sent along with the body of the request (Z2, Z3, ..., Z12 or automatic) and also the sequential identifier of the vehicle where the code was read. For the *intermediate check-in* request, apart from the sequential identifier of the vehicle, the identifier of the trip, that the user wants to add a checkpoint to, shall also be sent. Finally, the *check-out* request requires the identifier of the trip and also the sequential identifier of the station where the code was read. Next, the details of each checkpoint type will be briefly described.

– ***Check-in***: This method receives a request to perform a check-in, and it is in this method where a trip is created, along with its first checkpoint, the check-in checkpoint. If the ticket type that was passed as parameter is not automatic (the type in which a check-out is required), then first the method verifies if the user currently has a trip with an active ticket, that can receive the checkpoint, thus sparing a ticket to the user. If a ticket exists, then the checkpoint is processed as an intermediate check-in, otherwise the method proceeds to validate a ticket the user has. After this step is performed, a trip is created and the created checkpoint is added to the new trip. The station that is added as the checkpoint station, is calculated by determining the closest station to the user's location, and verifying if it is within an acceptable radius. Figure 5.3 depicts this process at a high level.

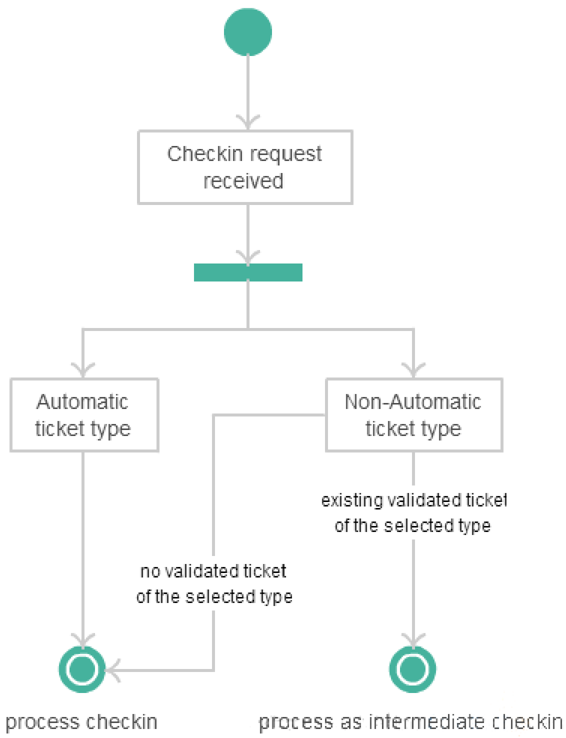

Figure 5.3: Check-in Process State Diagram

– ***Intermediate check-in***: This method simply creates an intermediate check-in checkpoint and adds it to the trip that was passed in the parameters. Similarly to the check-in method, the closest station to the user is used as the checkpoint station.

– ***Check-out***: The check-out checkpoint can be created for both automatic and non-automatic trips, being this step required for the former. Similarly to the previous method, this one creates a checkpoint of the type check-out, and adds it to the trip passed in the parameters. Finally, the station that is associated with the checkpoint is the station that is passed in the parameters. The location that is passed in the parameters is used to verify if the station is within an acceptable radius of the user's location.

Each sub-method, returns the trip and the created checkpoint. Finally, when checkpoints are being processed in a trip that requires check-out, the validity of the trip is verified, and in case it has expired the checkpoint type that is created is *maximum check-out*. This represents an automatic trip that has exceeded the maximum validity time, without having received a check-out.

5.3 Mobile Application

The mobile application is the component that is supposed to be used by the commuters, on their daily commute. This application serves as the client of the system, and uses the functionalities provided by the server.

The application was implemented for the Android Operating System (OS), due to the device available for development being an Android device and also because Android smartphones have a larger market share than the remaining counterparts [Cor15]. The OS version chosen to develop the application was the 4.1 version, named Jelly Bean, with API 16. This represents the minimum version that an Android device must have, in order to be able to install and run the application. This version was chosen in order to target a big number of devices, being in this case possible to reach 87.5% of Android devices [And15b], and also to allow the use of more advanced features in the development of the application, which is the case of the NFC functionalities.

The application itself was developed to support both QR Codes, and NFC tags. These codes contain information that has to be read by the user's device and there are two types of codes. The codes available inside the vehicles, have the check-in information and the information contained in them is "checkin|vehicle_id", in which *vehicle_id* is a number representing the sequential identifier of the vehicle. The codes placed in the stations are the check-out codes and the information contained in them is "checkout|station_id", being *station_id* a number representing the sequential identifier of that station.

Finally, the prototype currently supports two languages: English and Portuguese. Possible future work for the application would be to give support to other languages.

5.3.1 Libraries

In order to facilitate the development process of the mobile application, several open-source libraries were used. The most important are now presented and briefly explained.

- ***Retrofit***: *Retrofit* is a REST client for Android [Squ15], that simplifies the process of creation one in an Android application. It allows the creation of a REST Service, that communicates with a server, by simply declaring a Java interface, hence speeding up the development process.
- ***Realm***: Mobile devices may not be connected to the Internet at all times. Besides, this application will be mostly used outdoors, where data networks are used, and, as such, the least amount of requests should be sent to the server, so that the least amount of data can be used. With that in mind, the application should have a local database to cache some of the results fetched from the server. *Realm* was used with that purpose. It is a mobile database that is easy to use and "is much faster than an ORM, and is often faster than raw SQLite as well" [Rea15].
- ***Barcode Scanner***: This open-source library allows the easy implementation of QR Codes reading, by providing easy to use views that allow reading codes [Mag15]. It provides both ZXing and ZBar implementations, and for the purpose of this prototype the ZBar based view was used.

5.3.2 Functionalities

The developed application prototype allows its users to perform several actions that provide them with useful information and at the same time an easy to use process when validating tickets. At this stage, money issues were not taken into account, since this aspect is not important to determine the usability of this system among its possible users. Summing up, the biggest focus of the prototype revolved around the validation process and in the possibility of having multiple active trips.

One important concept of the system that should be explained is the concept of trip. Each user has its own active and past trips, and each trip can either be associated with a specific ticket type (e.g. Z2) or an automatic ticket, that requires the user to perform a check-out so that the system can calculate how much to charge for that trip. With that in mind, a trip represents an ongoing commute, in which the user is going from an origin station to a destination, and this trip can be used to legally travel in a vehicle. Each trip has checkpoints associated with it, which represent code scans by the user when entering a vehicle or after performing a check-out in a station.

Each functionality of the system is now explained, so that a general overview of what the application allows the users to do can be given.

- ***Login***: This functionality allows the users to create an account in the system and then to authenticate themselves in the application. To do so, users simply have to fill the email address and the password, and the system authenticates them. In case an account with that email address does not exist yet, one is created automatically. This was done in order to make this process easier in the case of the prototype and also to allow multiple accounts to be used in one smartphone. A future version of the prototype might require the user to fill a registration form, before being able to log in the system.

- ***Settings*:** This functionality allows the users to configure some local settings of the application and also the account name. The settings that are possible to configure are the following:
  - *Name*: This setting allows the user to change the name of its account, updating it in the server as well.
  - *Ticket Type*: With this setting, the user can configure the type of ticket that is automatically selected when performing a check-in. There are three major types of possible tickets that can be configured. The first is *Manual* which prompts the user with a list of all the possible ticket types, including *Automatic* every time the user checks-in. The second type is *Automatic* which creates a trip that requires a check-out. And the last type is any possible ticket type used in *Andante* cards (e.g. Z2, Z3, etc), thus automatically creating new trips with the configured type.
  - *Flash*: After reading several QR Codes during the laboratory testing of the application, it was possible to determine that when reading a code under different illumination conditions, the codes might not be read properly. In order to solve this issue, the application has the option of automatically turning on the camera's flash, when the illumination levels drops below a certain level, by using the light sensor available in most mobile devices. This *Automatic* mode is one of the options that is possible to be chosen when configuring the Flash Mode. The other two options are *On* and *Off* that make the flash be always on or always off, respectively.
- ***Active Trips*:** With the application, the user is able to see a list of all the trips that are currently active. As such, it allows the user to select which trip to use when boarding a new vehicle or performing a check-out in a station. When a check-in is performed, a trip is created and it is added to the list of active trips.
- ***Past Trips*:** The user also has the possibility of checking the past trips that were done, so that he or she has more available information about his own profile.
- ***Trip Details*:** Each trip has detailed information about the creation date, the expiry date, the associated ticket type and also the checkpoints that were added to the trip. Therefore, the application allows the user to check all these details by selecting a trip in the aforementioned trips' listings. Furthermore, if the user wants to add a new checkpoint to an active trip (e.g. when the user boards a new vehicle), he or she can do so by opening the trip details and selecting the *Checkpoint* option.
- ***Tickets*:** This functionality allows the user to list all the tickets that were purchased. The listing shows the amount of tickets owned for each type of ticket.

- ***Buy Tickets*****:** With the application, the user can also buy tickets. This can be done by selecting the number of tickets of different types that the user wants to acquire, and confirming the purchase action. This way, a single request can be used to buy different numbers of different ticket types.

- ***Checkpoint*****:** Along with the active trips functionality, this is the most important part and it allows the user to read both QR Codes and NFC tags. The user can either select the check-in option, where a check-in code is expected (inside a vehicle) and when one of these codes is read a new active trip is created and the user can legally travel with that trip, thus serving as the ticket validation step. On the other hand, as earlier referred, the user can also read a code by selecting the *Checkpoint* option when viewing the details of a trip. In this case, both *check-in* or *check-out* codes can be read, and the application interprets a *check-in* code as an intermediate check-in and *check-out* one as a check-out. When a *check-out* code is read in an automatic trip (required check-out), the trip is terminated and is not active anymore.

- ***Offline Synchronization*****:** In case the user's device is not connected to the Internet when reading a checkpoint, the application stores the new checkpoints locally. This is valid for each type of checkpoint, creating local (offline) trips when needed. Once the user connects the device to the Internet, while the application is open, all the locally stored checkpoints are sent to the server in order to synchronize the local information with the server. This allows the application to not be dependent on the existence of an Internet connection.

Figure 5.4 shows the use case diagram of the application, so that what is possible to do with it can be more easily seen.

5.4 System's use flow

The normal flow of the mobile application will be exposed, so that a clear overview on how the system is supposed to be used can be provided. The following steps are an example of a use case, but different flows can be followed in the normal use of the application.

1. In case no user is currently logged in the application, the Login Screen will be presented to the user. In this screen, the user has to fill the login credentials, which are the email address and password, so that he or she can be authenticated in the application and get access to the available functionalities. As previously mentioned, in case an account with the inserted email address does not exist in the system yet, one will be created automatically when performing the login. Figure 5.5 shows the described login screen.

2. After performing the login, the user has access to all the application's functionalities. Most functionalities are accessible on the navigation menu, by swiping the finger from the left edge of the device to the right, or by pressing the 3-striped icon on the top left corner of the application screen. Using this menu, shown in figure 5.6, the user can select the *Active*

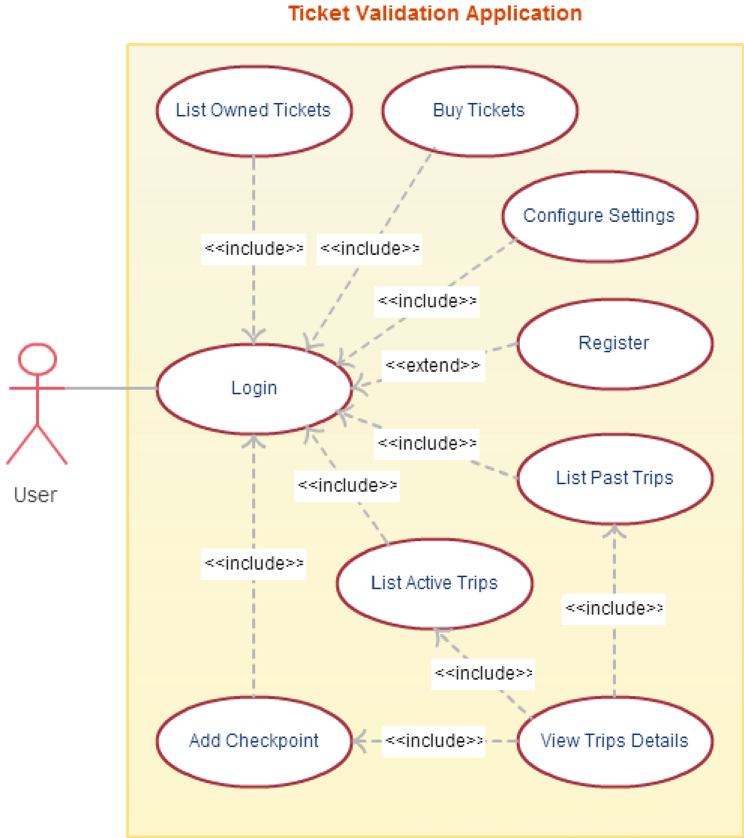

Figure 5.4: Use Case Diagram

Trips, *Past Trips*, *Tickets* and *Settings* options. Besides, the user can also choose to log out of the application by selecting the appropriate option: *Logout*.

3. At any time the user can choose to change the local configuration settings of its account and local application. One of the options that can be changed is the name of the user, by selecting the appropriate option in the Settings Screen. The other options, that were earlier explained, allow the user to configure the default ticket type when performing a check-in and the flash configuration option. Figure 5.7 shows all the available options in this screen, showing the currently selected value below each option.

4. When the user selects the *Active Trips* option in the menu, he or she can see the currently active trips, showing the expiration date, the last station in which the trip was validated and also the ticket type associated with it, or *Checkout Required* in case it is an automatic trip. From this menu we can click the plus button, available in the bottom right corner of the screen, in order to create a new trip by reading a check-in code. Figure 5.8 shows the list of active trips and also the described plus button.

5. Assuming a new trip is to be created, the user presses the aforementioned plus button and is taken to the screen where a QR Code, or NFC tag, can be read. This screen is shown in

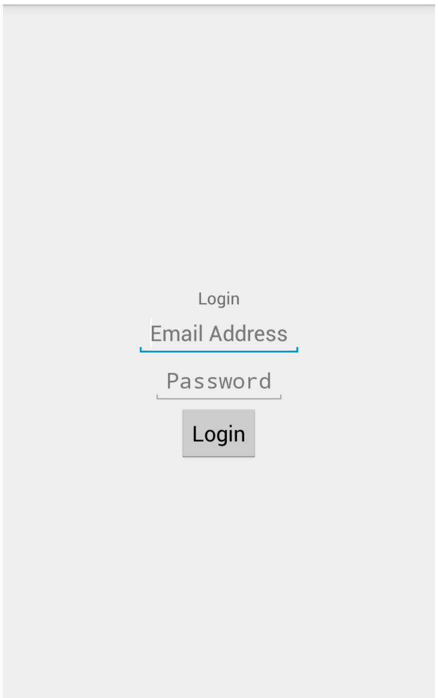

Figure 5.5: Login Screen

figure 5.9.

6. After a valid check-in code is read a new trip is created and the user can now view the details about this trip. The details include the created date, expiration date, ticket type and also the checkpoints associated with that trip. Apart from viewing this information, the user can also choose to add a new checkpoint by pressing the *checkpoint* button available in the bottom of the screen. After pressing this button, the screen that is shown is the same as in 5.9. In case the user reads a *check-in* code, the new point is labeled as *Check*. Otherwise, if a *check-out* is read, the new checkpoint is labeled as *Check-Out*. Apart from the label, each checkpoint also shows the station associated with the reading and also the time at which the code was read. All these details can be seen in figure 5.10, which is an automatic trip, identified by the *Checkout Required* text shown.

7. Now we can imagine the user has read a check-out code. The detailed view screen of the previous trip now has a *Check-Out* checkpoint and it has already expired, since a *Check-Out* point was added, as it can be seen in figure 5.11.

8. Another functionality that is available in the application is the *Tickets* one. When the user selects the *Tickets* option in the menu, a screen with the tickets the user currently owns is shown. Figure 5.12 shows this screen, showing that each item has the ticket type and the amount of tickets of that type. Furthermore, in case the user wants to buy more tickets, the user can do so by pressing the *Buy Tickets* available in the bottom of the screen.

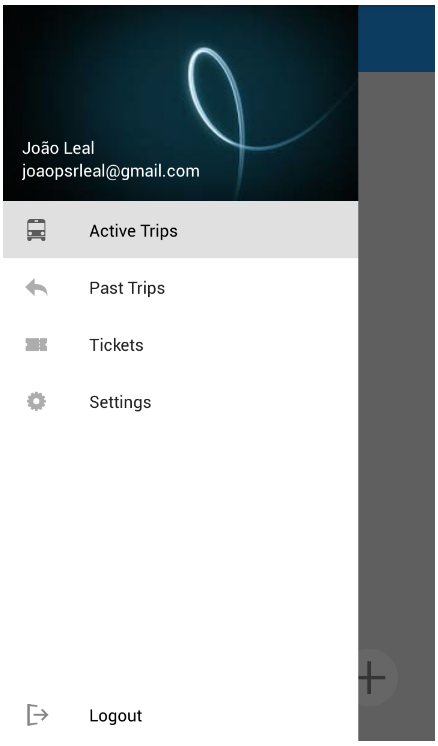

Figure 5.6: Navigation Screen

9. After pressing the *Buy Tickets* button, the user is presented with a screen that allows the purchase of tickets. This can be done by pressing the plus or minus icons on the intended ticket type item. As an example, if the user wants to buy 2 Z2 tickets and 1 Z3 ticket, he or she should press twice on the plus icon shown on the Z2 box and once on the Z3 box. As a result, these boxes show the values 2 and 1, on the Z2 and Z3 boxes, respectively, showing the amount of tickets being bought. After all the selections have been finished, the user needs to press the *Buy Tickets* button shown in the bottom right corner of the screen, thus purchasing the tickets and being redirected to the *Tickets* screen. If the user wants to clear all the selections, that can be done by pressing the *Reset* button, found next to the *Buy Tickets* button. Figure 5.13 shows the described selection and screen.

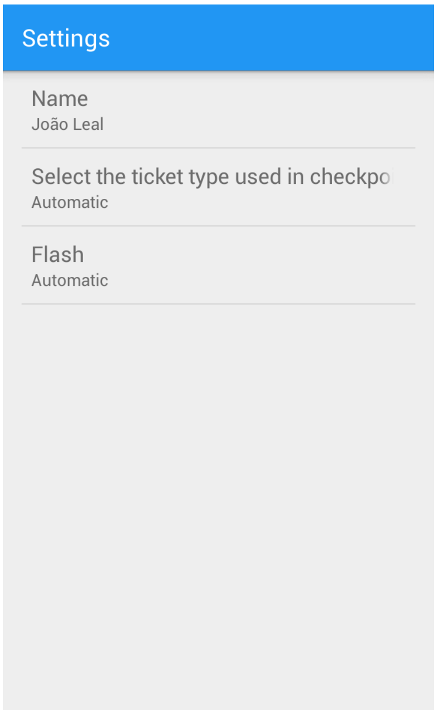

Figure 5.7: Settings Screen

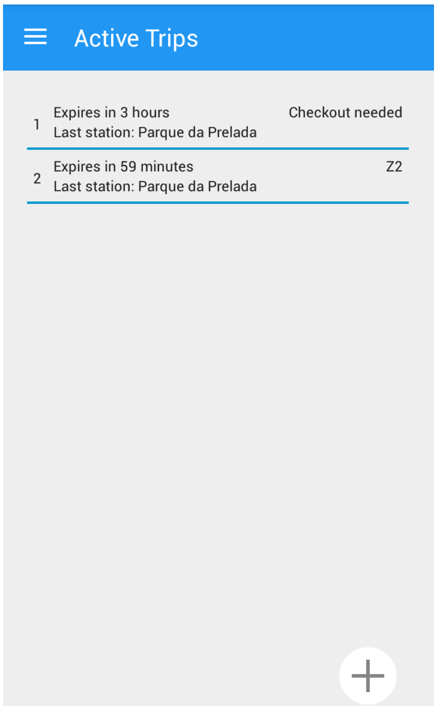

Figure 5.8: Active Trips Screen

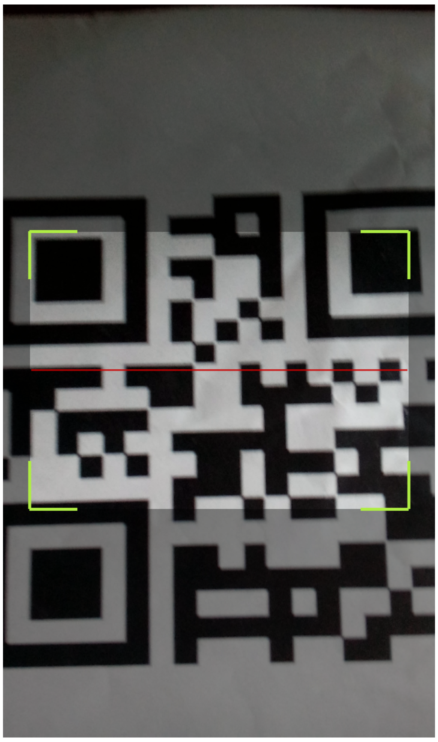

Figure 5.9: Code Reading Screen

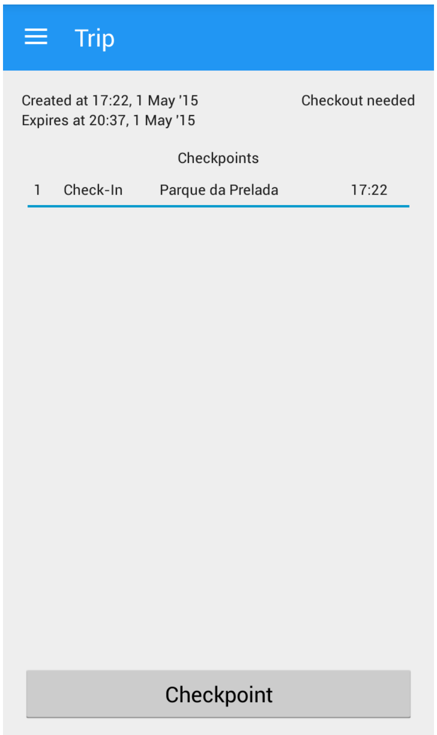

Figure 5.10: Trip Details Screen

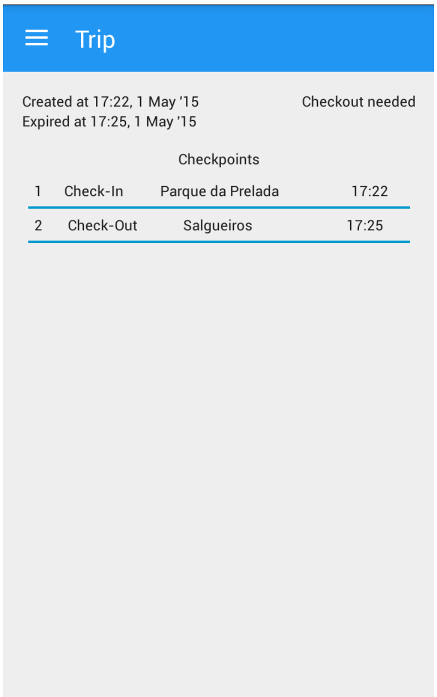

Figure 5.11: Expired Trip Details Screen

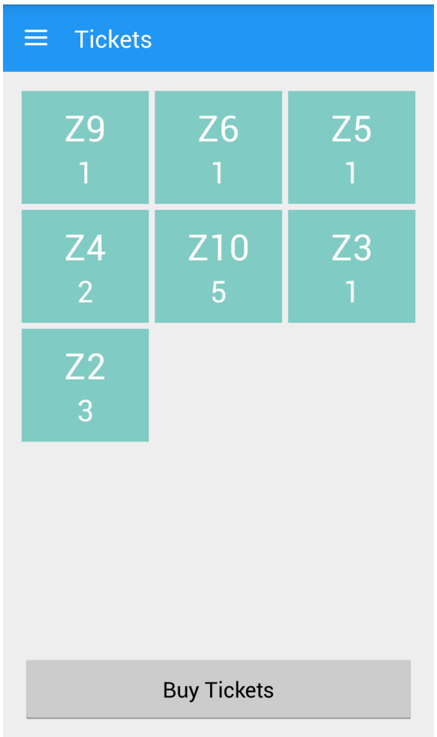

Figure 5.12: Owned Tickets Screen

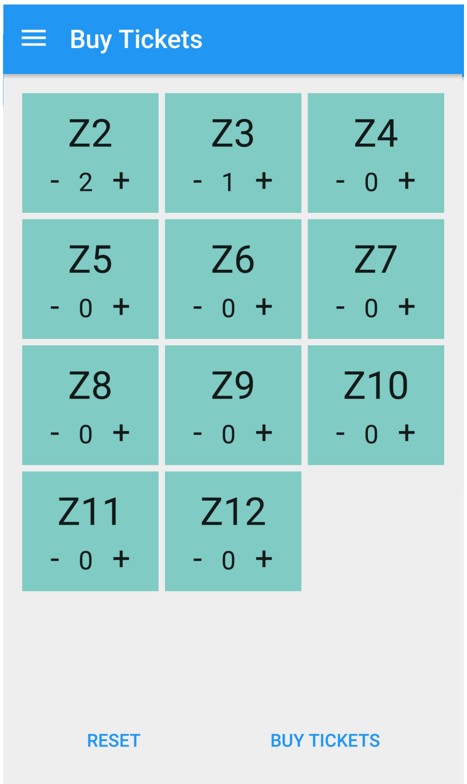

Figure 5.13: Buy Tickets Screen

Chapter 6

Evaluation

Since the developed system is supposed to be valid for a possible integration in a real environment, with real users, it must be tested in both such an environment and in laboratory, to find out possible improvement opportunities and also receive some feedback from potential users. The laboratory tests were done before the real environment tests so that the reliability of the application could be ensured before the field study. Besides, laboratory tests allowed the testing of the prototype under different conditions and in a more controlled environment. As for the evaluation done in a real environment, it was done with people who are potential users of the buses of STCP, so that more reliable feedback can be gathered.

6.1 Laboratory Testing

This section now presents the methodology and results of the tests performed in laboratory testing, in order to determine the reliability and better analyze the used technologies.

6.1.1 Methodology

Both QR Codes and NFC tags were tested under different conditions, in order to determine how they best work in a real environment. These tests were performed using a *Motorola XT926* mobile phone and their content was: *checkin|3*.

In order to analyze the performance of reading a QR Code, the speed of the reading process should be measured and evaluated. However, this process should be replicated under different circumstances, to emulate plausible public transport scenarios. Furthermore, the two QRCodes that were used to perform the tests were printed in a white sheet of paper, one of them measuring 5.82cm x 5.82cm and the second one doubling the size to 11.64cm x 11.64cm. These dimensions were used to fit existing infrastructures, such as buses or stops.

One of the factors that is prone to influence the reading of a QR Code is the ambient light available at that moment. In the tests, ambient light is measured in lux, which is the unit that measures the amount of light received by a sensor, and in this case the sensor available in the Android device was used for the tests. Two other factors that might influence the reading process are the size of the QR Code and the distance at which the code is read. Another aspect that might influence this process, is the movement involved. However, at this stage, movement was not considered in the tests.

In order to evaluate the performance of QR Codes under these conditions, both codes were placed under three different illumination levels: high (~80 lx), medium (~20 lx) and low (~5lx). Besides, a possible minimum level needed for reading a tag was also tested. Finally, the two codes were also read at different distances so that the influence that this factor has on the process could be determined. The distances used in the tests were: 1m, 0.75m, 0.5m and 0.25m.

Similarly to QR Codes, the main aspect that should be evaluated when analyzing the performance of NFC tags is the speed of the reading process. However, the factors that influence the process of reading NFC are not the same as the factors that influence the reading of QR Codes. On NFC, the most important aspect that should be tested is the existence of a material between the reading device and the tag. In order to do so, the same NFC tag was read with different materials in between. The first test was performed without any material, the second was performed using a 1.5cm plastic piece in between, the third a 3cm wooden surface and the last was performed on a 7cm thick double-glass window. An NDEF message, an NFC data format, with 9 bytes was written in the tag and the default tag reading Android application was used.

Table 6.1 summarizes the different test scenarios.

Table 6.1: Laboratory test scenarios

Scenario Number	**Technology**	**Condition**	**Values**
Scenario 1	*QR Codes*	Illumination	• ~80 lx • ~20 lx • ~5 lx
Scenario 2	*QR Codes*	Distance	• 1m • 0.75m • 0.5m • 0.25m
Scenario 3	*NFC*	Material & Distance	• No material - 0cm • Plastic - 1.5cm • Wood - 3cm • Double-glass window - 7cm

6.1.2 Results

The results from the tests are now presented for the two evaluated technologies.

- **QR Codes:** The reading speed of the QR Codes in different light levels was quite regular, not varying much when different illumination levels were available. It was however possible to determine a minimum level needed to perform the readings. This level is 4 lx, and it corresponds to the minimum lighting level needed for the reading process to be performed successfully. When the codes were in an environment in which the illumination is lower than this value, the codes were not possible to be read. This might be a challenge in bus stops at night with low lighting, requiring an extra light source, such as the flash.

In addition, the two codes that were used were read at different distances and it was determined that the maximum distance that the smaller one (5.82cm x 5.82cm) could be read, is approximately 0.5m (M=589.5ms SD=232.6ms). As for the bigger one, this distance is approximately 1m (M=502ms SD=18.4ms). In this case, the consequence of doubling the size of the code, resulted in doubling the maximum distance at which the code can be read. Also, when the code is read nearby, the reading process might be inconclusive, therefore the minimum distance for successful reading is dependent on the code size. Figure 6.1 shows a chart presenting the average reading speed of the two codes, at different distances. In the cases where a column is not shown, it represents a case where the code was not read.

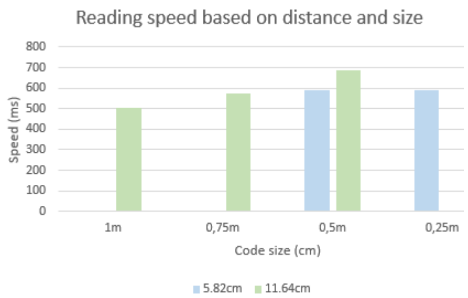

Figure 6.1: Reading times of the QR Codes, based on distance and size

Figure 6.2 presents the average results of reading the codes under the previously described illumination conditions, in which only one column was used to represent the corresponding gathered values, for both code sizes.

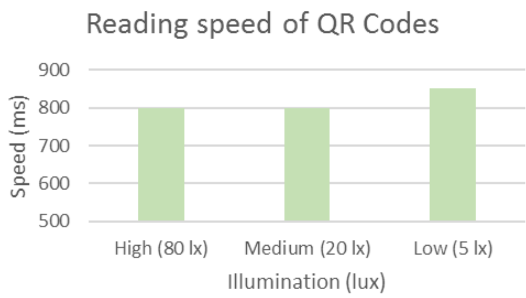

Figure 6.2: Reading times of the QR Codes, under different illuminations

It is possible to conclude that the reading speed is approximately the same under different illumination and distances. This shows that when appropriate conditions are met during the reading process, stable reading speeds can be obtained. Besides, in the context of public transportation, the size of the QR Codes should be bigger or equal than 11.64cm, so that more than 1 person can read them at the same time. The results only account for the moment in which the camera is being pointed at the code, assuming the camera and the application are on.

- **NFC:** In similarity with the QR Codes, the reading speeds that were achieved while performing the reading of NFC tags were stable. When reading the tags using the described materials, similar average reading times were obtained, with the exception of the glass test. In this test, due to the properties of the barrier, the mobile device could not read the code. Figure 6.3 presents the average results of these readings.

  It is possible to observe that the bars shown in the chart are almost at the same level, except the last one that does not show any value, since it was not possible to perform the reading process.

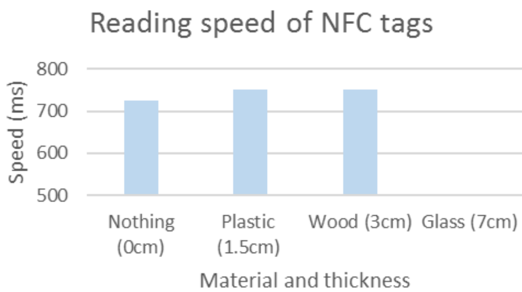

Figure 6.3: Reading times of the NFC tags

6.1.3 Conclusions

After performing the laboratory tests of the chosen technologies, it was possible to conclude that either technology can be used to implement the mobile ticket validation system in public transportation, under different conditions. If read properly and in the appropriate conditions, both NFC tags and QR Codes have similar reading speeds.

Since QR Codes are going to be the object of the evaluation in the field study, some considerations about them should be taken. They should have a size of 11.64cm in order to allow multiple users at the same time to read the code, since the codes can be read at a distance greater than 0.5m. Furthermore, the best possible illumination conditions should be met, which can be achieved by placing the codes as close to the windows as possible. The field study will allow the testing of these conditions and the usability of reading QR Codes in a real environment. Finally, the distance and the angle of reading the code might affect the reading speed, being this dependent on the user performing this action.

6.2 Field Study

The specification of the field study that was done is now presented, describing its flow and methodology, and also its results and feedback that were collected during this evaluation period.

6.2.1 Experiment Description

The main goal of the experiment was to determine the usability of the solution and to get feedback from possible users of the system. In order to achieve that, 6 students from the Faculty of Engineering of the University of Porto were selected and contacted to test the developed application in a bus, by using the mobile phone and QR Codes to perform the whole process of traveling in a bus, including the boarding, the ticket validation and also the check-out step, when leaving in the intended station. The size of the testing sample is not larger due to the lack of resources, which would be needed to perform a larger scale experiment. However, a group of 6 people is very close to the ideal number of participants in a usability test, which is 5, according to Nielsen [Nie15a, Nie15b].

Apart from the test itself, two questionnaires were sent to the test participants, using Google Forms, and these can be found in figures B.1 and B.2 in the appendix section. The first questionnaire was sent before the experiment itself, and its purpose was to determine their current view on and use of public transportation. The participants were asked the following questions:

- Do you usually use public transportation?
- If you answered affirmatively to the previous question, what's the weekly frequency that you use it? (0 - 7 days a week)
- Do you identify any problems with the ticketing system of the transportation system that you use? If so, what are those problems?
- What's your level of interest in a ticket validation for public transportation that uses the smartphone? (0 - not interested, 5 - completely interested)

The second questionnaire was sent after the test, and its purpose was to get some feedback of the system from the participants. The participants were asked the following:

- How would you qualify the ease of use of the system used in the tests to perform ticket validation? (0 - very hard, 5 - very easy)
- Which solution do you prefer: the existing Andante system or the proposed solution that uses QR Codes and the smartphone?
- In which way would the new solution impact your use frequency of public transportation? (increase, maintain even though the new solution is preferred, maintain even though the current solution is preferred, decrease)

- Do you have suggestions for possible improvements of the created solution?

As for the test itself, the participants were supposed to have the application previously installed on their smartphones and use it to perform a complete bus trip. The bus line 300, belonging to STCP, was used, and the participants boarded the bus in the stop *Escola Superior de Educação* and validated a ticket using their smartphone, by reading one of 2 check-in QR Codes placed inside the bus. After that, they left the bus after 2 stops, in the *Faculdade de Economia* bus stop, and read the check-out code placed there, as it can be seen in figure 6.4. The users had the freedom of deciding whether to have Internet access during the whole process or not, since the application supports both online and offline reading. The users were contacted both personally and using a Facebook Group Chat, so that the communication between everyone could be faster and easier.

Figure 6.4: Map showing the stops covered by the field study

In the case of this experiment, QR Codes were used due to its cost and the ease of printing, but the same test could be performed by using NFC tags, since the developed application was developed to support this technology as well.

6.2.2 Results

Now, the results obtained from the experiment are presented and analyzed. They were collected from the questionnaires' results and also from oral feedback received from the testers. Even though such a small sample does not provide statistically significant results, the gained insights may be used in the future to perform field tests at larger scales.

The answers from the first questionnaire made it possible to determine the types of public transportation users that were going to participate in the test and also to identify the possible problems in the current ticketing solution (Andante). Analyzing the answers and table 6.2, it is possible to see that two of the testers do not use public transportation frequently, while the remaining four are frequent users. Of these four users, two of them use public transportation five days a week, while the remaining two use it in average one day a week. This group of users is quite heterogeneous, which is advantageous to perform the intended test, since each user has a different perspective on the use of public transportation. As for the interest in a ticket validation system that uses the smartphone, the average interest is 4, out of 5, which shows that there is a high interest in such a system, as seen in table 6.2.

Table 6.2: Table showing whether each participant uses public transportation or not, the average weekly number of times they use it and also their interest level in a mobile ticketing solution

User	**Uses public transports**	**Weekly average**	**Interest level**
User 1	Yes	5	5
User 2	No		4
User 3	Yes	1	3
User 4	Yes	1	3
User 5	Yes	5	5
User 6	No		4

Finally, the testers identified several problems with the existing ticketing system, and the following list presents them:

- There is the possibility of forgetting whether the ticket was validated or not.
- Sometimes it might be cumbersome having to take the wallet from the pocket, take the Andante card from it, validating the ticket and then putting everything back again.
- It might be difficult to plan the trip (e.g. correct number of zones).
- If the person does not have money, it might not be possible to buy tickets.
- In case the charging machines are broken, it is not possible to charge tickets.
- In the bus case, if the person does not have a charged Andante card, it is more expensive to buy a single ticket with cash.

From the identified problems we can see that there are many opportunities of improvement in public transportation, and the developed system tackles all of the identified problems.

As for the answers from the final questionnaire, the results obtained were quite consistent. The average evaluation for the ease of use of the system was 3.5, which means that the system is easy to use, even though there is possible room for improvement, as seen in figure 6.5. As for the preferred solution, all but one tester answered that they preferred the new solution. Furthermore, all but 1 tester answered that they would maintain the use frequency of public transports even though they preferred the new solution. The tester that did not answer this, was the one that preferred the existing solution and his or hers answer was that the use frequency of public transportation would be maintained, even though the existing solution is preferred.

Finally, some users gave some suggestions for possible improvements and future development of the solution:

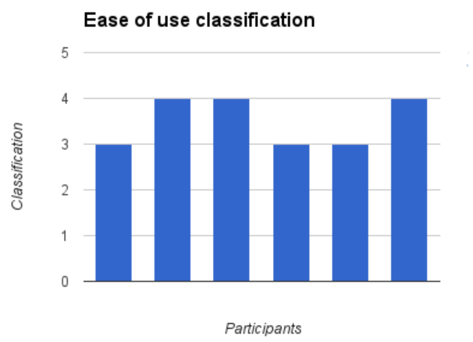

Figure 6.5: Chart representing the ease of use of the solution

- This solution should not replace the existing solution, but it should be an alternative to the existing solution.
- The solution could be further expanded, by adding other functionalities like schedule information or trip planning.

At last, the testers gave some oral feedback in the day of the testing. Most of them stated that they found the application to be quite useful and to be appealing. Nonetheless, there were some problems while reading the QR Codes, since the correct position and distance to the code had to be found. This was one of the major problems identified in the solution, the fact that QR Codes might be hard to read, which might take some time if the user does not read the code in the correct position and if the illumination conditions are not ideal at the moment of the reading. This issue most likely influenced the evaluation of the ease of use of the application, which has an average of 3.5. If this process was simpler and faster, the value of this evaluation could be increased.

6.2.3 Conclusions

After gathering the results from the experiment, it is possible to conclude that the experiment was quite successful, since it allowed to determine if there is real interest in a mobile ticketing system and whether the developed solution is feasible or not. By analyzing the results, we can conclude that there is interest in the use of a system that uses the smartphone to handle the ticketing operations. The mobile ticketing solution is preferred over the existing one, even though it has some caveats related to the QR Codes technology. These caveats are the possible slow reading process, when the reading is not done in the correct conditions: distance, position and illumination.

The proposed solution is feasible and most testers deemed the solution to be quite useful and they would prefer using it than the current Andante solution. The solution can be further expanded and improved, by adding new functionalities like the ones the experiment's participants suggested and possibly using NFC tags instead of QR Codes, as long as there is the possibility to cover the cost increase.

Chapter 7

Conclusions

Throughout this dissertation several aspects regarding the implementation of a ticket validation solution, in public transportation, using the smartphone were studied and analyzed, with the purpose of determining whether such a solution can be designed and implemented in a real company, with the least possible cost. The case of Porto's public transportation system was used as an example.

Several technologies were studied and compared (NFC, QR Codes, Location Data and Bluetooth) at cost, usability and reliability levels, in order to create a solution that used one or more of these technologies, at the least possible cost while maintaining a good usability level.

It was possible to conclude that location data alone was not reliable enough to be used in a solution, since the location information might not be accurate and available at all times. Nonetheless, the location information is important for a ticket validation solution, to perform the validation itself, based on the user's location, or to perform cross-validation of the information sent by the user's device to the server. One, or more, of the remaining technologies should then be used, and the selected one to be implemented in this case, mostly due to its cost and availability in users' devices, were QR Codes. These codes' distribution and maintenance are quite cheap, allowing a solution that uses them to be scaled up while maintaining a low cost. As an alternative, NFC can be used at the expense of a slightly higher cost

Testing the developed solution made it possible to validate its feasibility in a real scenario, which proved that the designed solution is preferred over the existing one. The system was tested with a STCP bus, which is the operator responsible for the buses in Porto's transportation system. Furthermore, it was possible to gather suggestions and feedback from possible real users of the system, which are useful to further understand the value of the designed solution, and possible improvement options.

We can conclude that the implementation of a ticket validation solution for public transportation, that uses the smartphone, is feasible. One of the main goals of this dissertation was to come up with a solution that used the smartphone, and its technologies, that was cheap and at the same time reliable and easy to use. And this goal was accomplished, as it can be seen by the results of the experiment. Additionally, it is possible to conclude that in order to come up with a solution that does not have high costs, the topology and size of the transportation network should be taken into account. QR Codes, along with Location data, are the technologies that allowed to design a cheap and reliable solution. As aforementioned, an alternative to QR Codes are NFC tags, since the reading process is easier and the information that both technologies store is similar, thus making the information interpretation process similar. Another important conclusion drawn from this work, was that the best technologies to implement a system as the one studied here will not always be the same. BLE and Beacons are a quite recent technology and it is expected that its price will lower and that it will become more reliable and stable, making it possible for this technology to be more beneficial than QR Codes and NFC in terms of cost and ease of use. Summing up, QR Codes and NFC are the ideal technologies in the short term, while BLE is likely to become better in the long term.

This work also opens the possibility for future work, by further improving and expanding the implemented solution or by creating new solutions based on the 3 proposed ones. Moreover, the knowledge produced and gathered in this document allows future research to be done on top of the produced work.

The goals of this dissertation can be deemed to have been successfully accomplished, and this work contributes to the scientific world by providing a comparison between the 4 studied technologies at a usability and cost levels, and by studying different possibilities of using the smartphone, and its technologies, in the context of public transportation. One of the achieved conclusions of this dissertation was that there is interest in the implementation of a ticket validation system using the smartphone. Furthermore, creating a system that is easy to use for the users and that has low distribution and maintenance costs for the operators would be beneficial for both sides. The dissertation contributes to the existing knowledge on the fields of ubiquitous computing and virtual ticketing, which are areas that might see scientific advancements in the future.

Finally, two papers and one workshop were written and submitted during the course of this dissertation, which contributed to the advancement of the knowledge in these areas. One paper was submitted to the Seventeenth Portuguese Conference on Artificial Intelligence (EPIA 2015) [LCCG15b] and the other to the Eighteenth IEEE International Conference on Intelligent Transportation Systems (ITSC 2015) [LCCG15a]. As for the workshop, it was submitted and accepted in the ITSC 2015 conference [LCCG15c].

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Appendix A

Application Screenshots

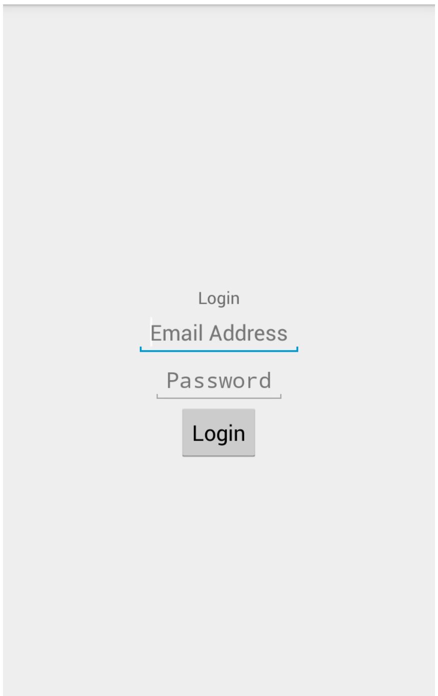


Figure A.1: Login Screen

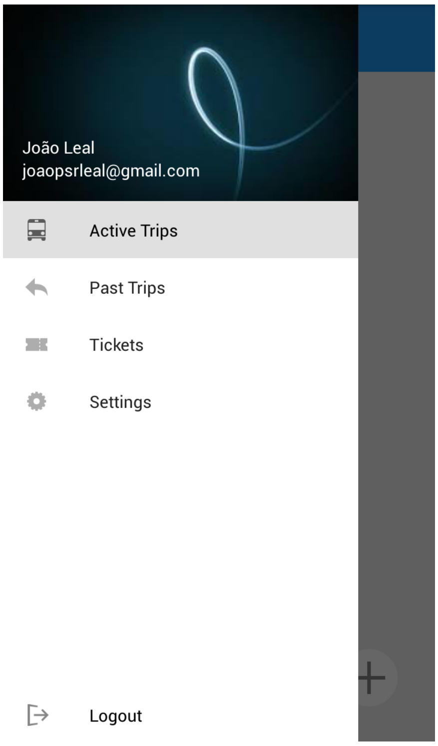


Figure A.2: Navigation Screen

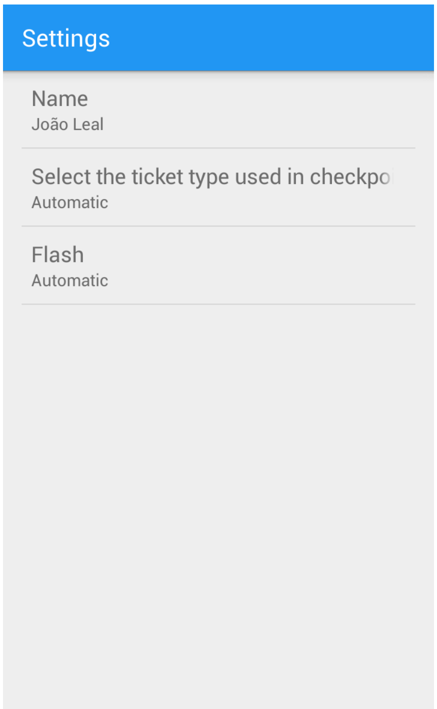


Figure A.3: Settings Screen

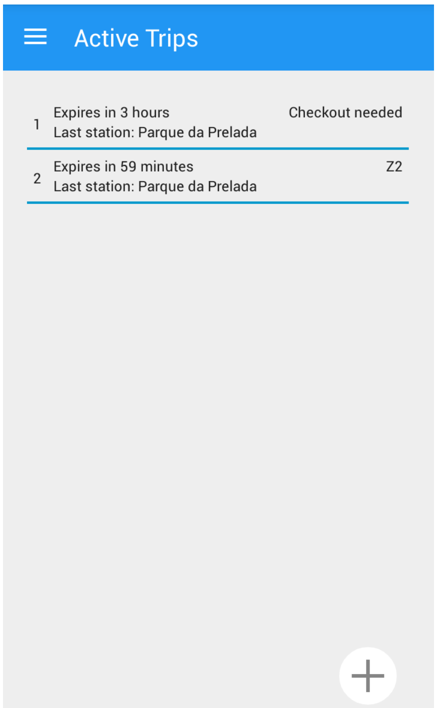


Figure A.4: Active Trips Screen

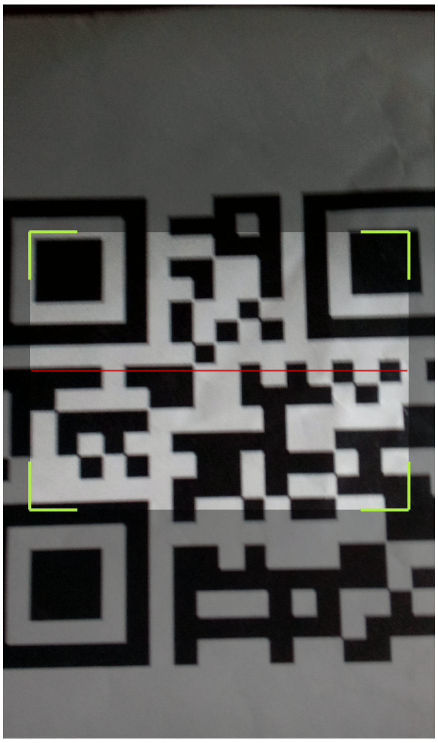


Figure A.5: Code Reading Screen

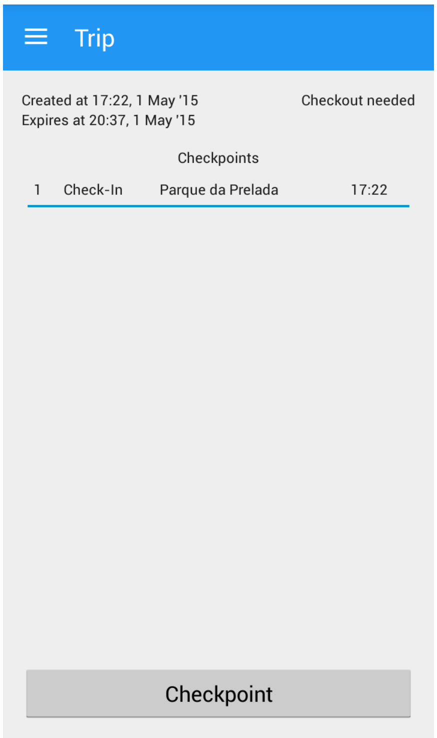


Figure A.6: Trip Details Screen

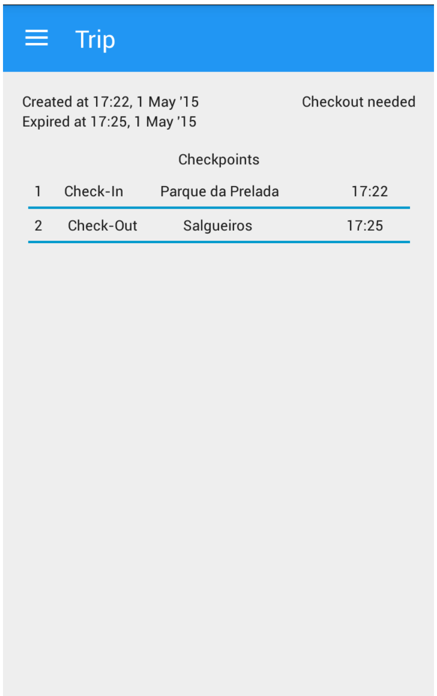


Figure A.7: Expired Trip Details Screen

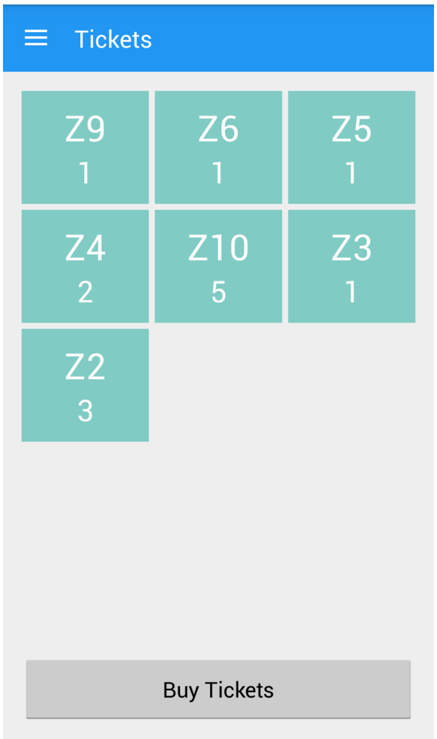


Figure A.8: Owned Tickets Screen

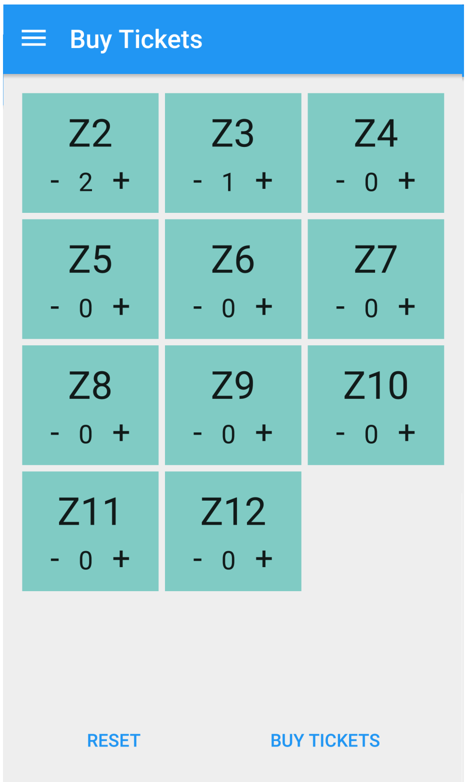
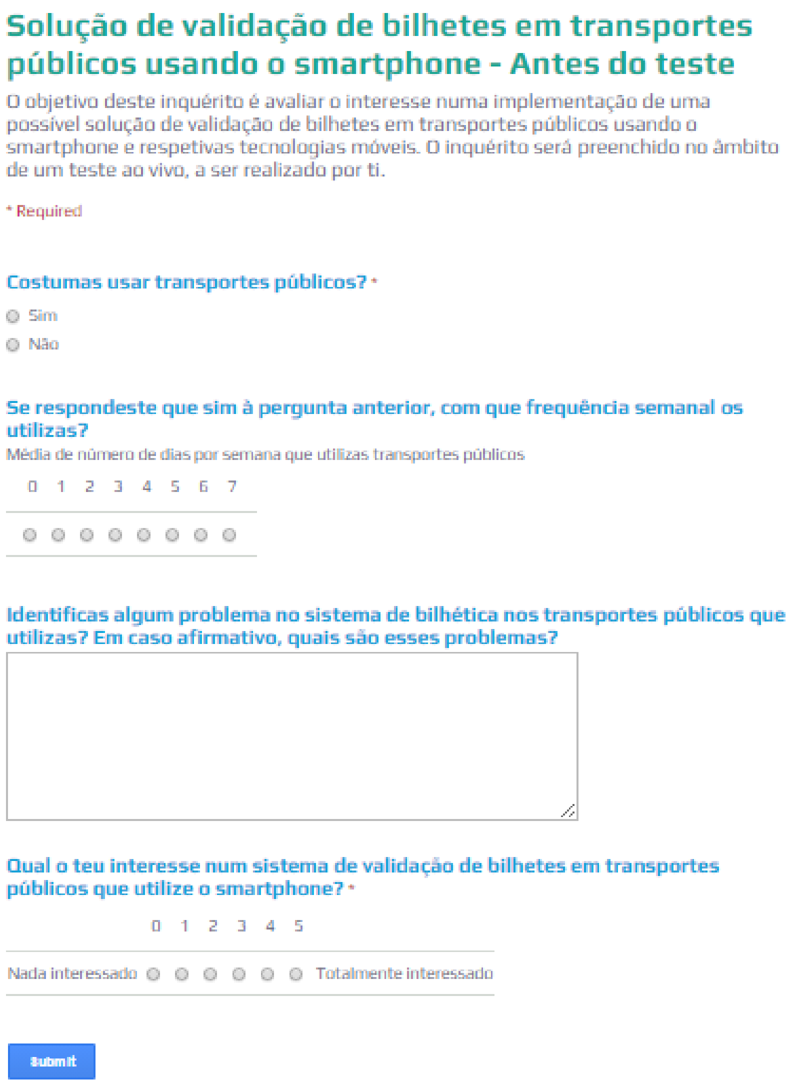


Figure A.9: Buy Tickets Screen

Application Screenshots

Appendix B

Questionnaires



Solução de validação de bilhetes em transportes públicos usando o smartphone - Antes do teste

O objetivo deste inquérito é avaliar o interesse numa implementação de uma possível solução de validação de bilhetes em transportes públicos usando o smartphone e respetivas tecnologias móveis. O inquérito será preenchido no âmbito de um teste ao vivo, a ser realizado por ti.

* Required

Costumas usar transportes públicos? *

- Sim
- Não

Se respondeste que sim à pergunta anterior, com que frequência semanal os utilizas?

Média de número de dias por semana que utilizas transportes públicos

0 1 2 3 4 5 6 7

Identificas algum problema no sistema de bilhética nos transportes públicos que utilizas? Em caso afirmativo, quais são esses problemas?

Qual o teu interesse num sistema de validação de bilhetes em transportes públicos que utilize o smartphone? *

0 1 2 3 4 5

Nada interessado — Totalmente interessado

Submit

Figure B.1: Questionnaire sent before the field experiment (in Portuguese)

Solução de validação de bilhetes em transportes públicos usando o smartphone - Depois do teste

O objetivo deste inquérito é avaliar o interesse numa implementação de uma possível solução de validação de bilhetes em transportes públicos usando o smartphone e respetivas tecnologias móveis. O inquérito será preenchido no âmbito de um teste ao vivo, realizado por ti.

* Required

Como identificas a facilidade de utilização do sistema usado na validação de bilhetes? *

	0	1	2	3	4	5	
Muito difícil	○	○	○	○	○	○	Muito fácil

Qual a solução que preferes: o sistema Andante existente ou a solução proposta que utiliza o smartphone e QR Codes? *

- ○ Sistema Andante
- ○ Solução Mobile

De que forma esta nova solução afetaria o teu grau de utilização dos transportes publicos? *

- ○ Aumentaria
- ○ Manteria (apesar de preferir a solução proposta)
- ○ Manteria (por preferir a solução existente)
- ○ Diminuiria

Tens sugestões para possíveis melhorias à solução desenvolvida?

Não são esperadas sugestões relativas à qualidade visual ou robustez da aplicação desenvolvida

Submit

Figure B.2: Questionnaire sent after the field experiment (in Portuguese)

Appendix C

Accepted Paper

Accepted Paper

Exploring ticketing approaches using mobile technologies: QR Codes, NFC and BLE

João Leal, Rui Couto
Faculty of Engineering of the University of Porto,
Department of Informatics Engineering
Porto, Portugal
joao.leal@fe.up.pt, rui.couto@fe.up.pt

Pedro Maurício Costa, Teresa Galvão
Faculty of Engineering of the University of Porto,
Department of Industrial Engineering and Management
Porto, Portugal
pmcosta@fe.up.pt, tgalvao@fe.up.pt

***Abstract*— There is a growing interest in integrating public transportation with the smartphone and mobile ticketing provides just that. To do so, different technologies can be used, such as Near Field Communication, Quick Response Codes and Bluetooth Low Energy. This paper explores the possibility of implementing a mobile ticketing solution, with focus on the ticket validation process, using these technologies. They are analyzed and compared at different levels and two possible approaches proposed. Both solutions are presented in terms of infrastructure and maintenance cost, as well as passenger interaction and benefit. The feasibility and performance of the technologies is analyzed and presented in the context of the proposed approaches. As a result, a mobile ticketing solution can be implemented using different technologies, and their choice depends on factors such as the available funds, the intended interaction level, performance and the size of the target audience.**

***Keywords*— ble, bluetooth, qr codes, public transport, mobile ticketing solution, nfc**

I. Introduction

Public transportation (PT) is growing increasingly important in the context of modern society. Constantly growing cities are making it very difficult to arrive on time and save up on moving, problems that can be solved using PT services. These type of services are not focused on profit [1] but they can be optimized in order to reduce costs.

The ticketing infrastructure is critical for the success or failure of a PT service. It is the main point of entry of revenue and also one of the main points of exit of revenue in the form of investment and maintenance. This paper focuses on exploring this component of the infrastructure within the context of the two major PT operators in Porto, Portugal: Metro do Porto – light-rail operator with 81 stations and 102 vehicles [2] – and Sociedade de Transportes Colectivos do Porto (STCP) – bus and tram operator with 2651 stops and 473 vehicles [3].

Recent technological advances have allowed the adoption of powerful mobile devices and ubiquitous connectivity. This is triggering a change in the way that users interact with computers: the human-computer interaction paradigm is changing – the personal mobile devices are becoming portals to cloud-based repositories [4]. There are several technologies that people can use to interact with their surrounding context by using their mobile devices, such as Near Field Communication, Quick Response Codes and Bluetooth Low Energy.

The focus of this project is to determine how these technologies and the inherent ubiquitous connectivity revolution can improve the ticketing infrastructures, namely the ticket validation.

This document provides an overview of the current ticketing system of the Metro do Porto and STCP operators. Then, an analysis and comparison between the technologies is presented, leading to two proposals for improving the ticketing systems. Next, technology performance tests are described and analyzed. Finally, the conclusion highlights the key factors of each technology and a discussion presents main benefits and ideal scenarios for the deployment of both proposals.

A. Porto's Public Transport operators

The main companies operating public transports in Porto are Metro do Porto and STCP. The multi-modal ticketing infrastructure is based on smart cards and is called *Andante* [5]. It is an ungated system, meaning that the user does not have to check-out, only check-in.

For the user, some disadvantages arise, such as requiring pre-planning, aggravated by an irregular division of geographic zones and confusing ticketing schemes, making it harder to compute origin, destination and type of ticket.

The operators, on the other hand, are required to maintain highly specialized and costly equipment, and are not able to collect important information such as checkout locations, which would indicate and store a complete user trip, instead of only an entry point.

II. Technology study

The validation process using the smartphone can be made using different technologies. There are multiple existing solutions that aim to achieve this in an optimal way for both the users and the transport operators [6]. In the following sections, the technologies considered for the implementation of a mobile ticketing system are analyzed and compared.

A. Near Field Communication

Near Field Communication (NFC) is a short distance wireless technology, which comes embedded in some smartphones, that allows users to exchange information with

Figure C.1: First page of paper

a smart card or other NFC devices. A smart card is a card that contains a passive NFC chip that can be read by an active NFC device, which is called the reader. An NFC tag is, for instance, a small sticker containing an NFC chip, having stored data in it, that can be read or written by an active device.

The cost of this technology is not particularly high per piece [7], but it is the second highest cost technology presented in this paper. NFC has advantages like simple tag reading for a user, since they only need to unlock the phone and tap it on the intended tag, and the possibility of visually customizing the tags. It has the disadvantage of being a technology that is not available in every smartphone and not well known by the general public. This technology has been applied in public transportation before [6], with more focus on the touch-to-pay approach.

B. *Quick Response Codes*

Quick Response (QR) Codes allow the storage of information in a 2D barcode format, storing information both horizontally and vertically, thus carrying several hundred times more information than regular barcodes. These codes can be read by dedicated readers, or using smartphones as long as they have a camera and autofocus feature [8]. Also, QR Codes have the advantage of being easily created and can be printed using a regular printer, thus making the process of physical distribution not expensive. In fact, this process may be integrated in the workflow of existing schedules and maps at stops.

Similarly to NFC, QR Codes are also a technology that is mostly used to read a small amount of information from a code. QR Codes are the cheapest technology presented in this research since the maximum cost associated with it is the cost of printing paper.

Apart from its reduced cost, QR codes have the advantage of being supported by most smartphones [9], since only a camera with autofocus is required, and being more accepted by the general public [10], since they are widely used (e.g. magazines, advertising). One of its disadvantages is the fact that the reading process might be slower than NFC tags, since apart from unlocking the phone, the user also has to open the application and point the camera to the code. Also, the level of visual customization is more reduced than NFC tags.

C. *Bluetooth Low Energy*

Bluetooth is a wireless technology, that exchanges data over short distances using radio transmissions [11]. The most recent Bluetooth standard is called Bluetooth Smart, or Bluetooth Low Energy (BLE); it has several advantages over the traditional standard, such as lower power consumption and enhanced range [12, 13], and it is being adopted by the recently released smartphones. Another type of device that implements Bluetooth Smart technology is a beacon: a small device that periodically emits a Bluetooth signal, containing information, that can be picked up by another device that is scanning for Bluetooth signals [14]. When using specific tools, provided by beacon manufacturers, to develop a mobile application, it is possible, using the beacon signal, to determine the approximate distance to the beacon – called ranging – or to determine when the smartphone enters or exits the beacon's vicinity - called monitoring [15]. Beacons are more expensive than the previously presented technologies, having an average cost 60 times higher than the NFC most expensive counterpart [16], per unit. There are also lower cost options [17]. Beacons have the advantage of not requiring the user to interact with the smartphone in order to receive the signal being emitted, and also the fact that the information can be received at longer distances than NFC and QR Codes. Apart from the price, the biggest disadvantage is the fact that beacons require a power source, increasing installation/maintenance costs.

D. *Comparison*

The following table compares the technologies presented above:

TABLE I. TECHNOLOGIES COMPARISON

Technology	Price per unit	Advantages	Disadvantages
QR Codes	Very cheap	• High availability • High acceptance	• Higher user interaction • Lower customization
NFC	Cheap	• Visual customization • Low user interaction	• Lower availability • Not well-known
Bluetooth	Costly	• Long distance reception • No interaction needed	• Power source needed • High cost

Summing up, Bluetooth has the advantage of being more user friendly and automating the process of ticket validation, since it does not require interaction from the user, but has a higher cost of deployment. QR Codes on the other hand have a lower cost but require the highest level of interaction with the user. NFC tags are slightly more expensive than QR Codes, and cheaper than Bluetooth beacons, but the interaction process is more pleasant.

III. PROPOSED APPROACHES

Now, two possible approaches for a mobile ticketing system, in the context of Porto's public transportation system, are presented and discussed. Each approach uses different technologies: the first uses either QR Codes or NFC, due to their use case similarity, and the second uses of BLE and beacons. The focus of the presented approaches is the ticket validation process and the solutions account for the possibility of having check-in and check-out steps.

Figure C.2: Second page of paper

A. Approach 1 – Near Field Communication / Quick Response Codes

As aforementioned, the first solution uses QR Codes or NFC to implement the validation process, since both technologies consist of storing a piece of information that is actively read by a mobile device. The solution is described using QR Codes, but the implementation based on NFC tags is very similar and they may in fact complement each other. The check-in codes, or tags, will be placed inside the vehicle itself, requiring the reading process to happen while travelling. As a result, using the bus case as an example, each bus can have a number of codes (for example, 3 codes) placed inside, where the user would simply be required to read one in order to perform the validation step, namely the check-in step. In this solution, the check-out step is optional, and the user may pre-configure or choose at the time of check-in the ticket type being used: zone ticket or automatic ticket (postpaid solution – where the user is charged on his associated credit card).

When the automatic ticket option is chosen the check-out step is required, and the amount that is charged to the user is calculated from the route of the trip. In order to perform the check-out step, each station will have a check-out code with that specific purpose, thus identifying the station where the user finished the trip. Location data can be used to assess the user's real location, so that the system can verify if the user is indeed in a certain station.

Fig 1. First approach architecture [1 2 3 4 5]

B. Approach 2 – Bluetooth Low Energy

The second solution uses beacons and the monitoring concept presented previously. This solution envisions beacons to be placed at the stations of the network and inside the vehicles. Each beacon transmits a message that announces the vehicle / station type (light-rail or bus), the operating lines and identification. First, the user enters a station, which is detected by a smartphone application. If the user boards a vehicle, the entrance in the vehicle's region will also be detected. After boarding the vehicle, the user will be entering and exiting station range, while remaining in the vehicle range (stopping by the several stations in his course). If the user exits the vehicle region and the station region (therefore the user is no longer within the range of any beacon) the check-out is assumed. This flow allows to determine the entire course of the user: the check-in, check-out and intermediate points.

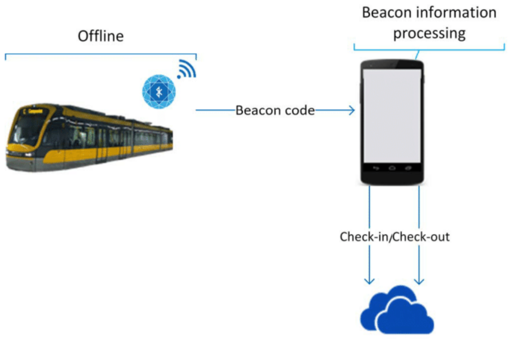


Fig 2. Second approach architecture

IV. Methodology

This section presents the testing methodology that was used to evaluate each technology's performance. Since each of them works in a different way, each experiment will be described separately. Every technology was tested in the same Android device.

A. QR Codes

In order to analyze the performance of reading a QR Code, the speed of the reading process had to be measured and evaluated. This process was reproduced under different circumstances, to replicate plausible public transport scenarios. Also, the two QR Codes that were used to perform the tests were printed in a white sheet of paper, one of them measuring 5.82cm x 5.82cm and the second one doubling this size. These dimensions were used to fit existing infrastructures, such as buses or stops.

One of the factors that is prone to influence the reading of a QR Code is the ambient light available at the moment. In the tests, ambient light is measured in *lux*, which is the unit that measures the amount of light received by a sensor. Two

[1] https://www.iconfinder.com/icons/99345/skydrive_icon
[2] http://smartcompanion.projects.fraunhofer.pt/
[3] http://ipsisnet.blogspot.pt/2012/12/metro-do-porto-pretende-reduzir-50-dos.html
[4] https://pt.wikipedia.org/wiki/Esta%C3%A7%C3%A3o_de_Baguim
[5] http:// NFCtags.com

Figure C.3: Third page of paper

other factors that might influence the reading process are the size of the QR Code and the distance at which the code is read. Movement can also influence this process however, at this stage, it was not considered in the tests.

In order to evaluate the performance of QR Code reading under these conditions, both codes were placed under different illumination conditions. Finally, the two codes were also read at different distances so that the influence that this factor has on the process could be determined. To perform the reading, an Android application, making use of an open source library based on Zbar[6], was used.

B. NFC

Similarly to QR Codes, the main aspect that should be evaluated when analyzing the performance of NFC tags is the speed of the reading process. However, the factors that influence the reading of NFC are not the same for the reading of QR Codes. On NFC, the most important aspect that should be tested is the material separating the reading device and the tag. In order to do evaluate this, the same NFC tag was read with different materials in between. The first test was performed without any material, the second was performed using a 1.5cm plastic piece in between, the third a 3cm wooden surface and the last was performed on a 7cm thick double-glass window. A message was written in the tag and the default tag reading Android application was used.

C. Beacons

The beacons used for testing were the Estimote beacons[7]. To test the beacons' performance an open space, simulating a wide station, was used (it wasn't possible to schedule real tests in the stations with the PT operators). A beacon was placed 3m high (Fig. 3 – left) and the readings were made in several locations along a 120m long corridor (Fig. 3 – right). The corridor was sectioned according to the distance from the beacon's location. The goal was to compare the real distance between a device and a beacon with the calculated distance (using the Received Signal Strength Indicator – RSSI – and Measured Power [18]). The readings were made using iOS and Android, with Estimote's official application for each platform[8 9]. This test scenario included the variation of the broadcasting range (broadcasting power intensity that translates to the maximum distance the signal can reach – coverage) [19] and advertising interval (the frequency in which packets are sent) [18, 20, 21, 22]. Samples were registered and then an average calculated.

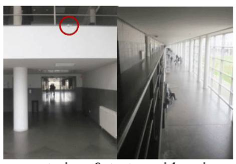


Fig. 3. Beacon placement view & test corridor view

[6] https://github.com/dm77/barcodescanner
[7] http://estimote.com
[8] https://itunes.apple.com/pt/app/estimote/id686915066?mt=8
[9] https://github.com/Estimote/Android-SDK/tree/master/Demos.Asd

An alternative test was executed with beacons – consisting on the measurement of time elapsed until the smartphone detects entry and exit of a beacon region – proximity detection [19]. The execution of this test required the demo application, provided by Estimote. Due to development limitations on the iOS platform (licensing requirements), these tests were performed on the Android platform only. However, given the different levels of development, the Android platform is expected to reveal worse performance than the iOS, thus covering the worst scenario. This test varied with the beacons' advertising interval but also with the smartphones' scanning and sleeping times [23]. Two samples for each variable scenario were taken. Then, the average between those samples was calculated. According to the documentation [23], a smartphone will detect the entrance on a region, in the worst case, in a complete cycle (sleeping time + scanning time).

V. RESULTS

The results from the executed tests are now presented and briefly analyzed.

A. QR Codes

The reading speed of the QR Codes in different light levels was quite regular, not varying much when different illumination levels were present. It was however possible to determine a minimum level needed to perform the readings. This level is 4 lx, and it corresponds to the minimum lighting level needed for the reading process to be performed successfully. When the codes were in an environment in which the illumination was lower than this value, the codes were not read successfully. This might be a challenge in bus stations at night, with low lighting, requiring an extra light source, such as the phone's flash. In addition, the two codes that were used were read at different distances and it was determined that the maximum distance that the smaller one (5.82cm x 5.82cm) could be read, is approximately 0.5m (M=589.5ms SD=232.6ms). As for the bigger one, this distance is approximately 1m (M=502ms SD=18.4ms). In this case, the consequence of doubling the size of the code, resulted in doubling the maximum distance at which the code can be read. Also, when the code is read nearby, the reading process might be inconclusive, therefore the minimum distance for successful reading is dependent on the code size. Fig. 4 shows a chart presenting the average reading speed of the two codes, at different distances. In the cases where a column is not shown, the reading failed.

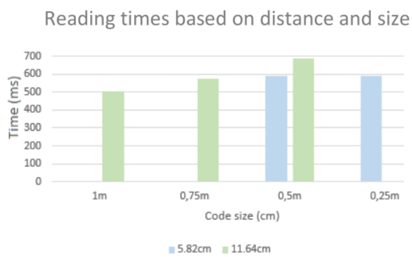


Fig. 4. Reading speed of the QR Codes, based on distance and size

Figure C.4: Fourth page of paper

Finally, in order to analyze the reading speed under different illumination levels, in the valid lighting conditions (>= 4 lx), three different levels were used: high (~ 80 lx), medium (~ 20 lx) and low (~ 5 lx). The codes were placed and read in different locations, that provided the Android light sensor with these values. Fig. 5 presents the average results of these readings, in which only one column was used to represent the values under the previous conditions, for both code sizes.

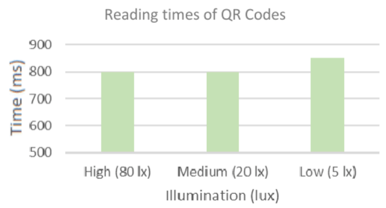


Fig. 5. Reading times of the QR Codes, under different illuminations

It is possible to conclude that the reading speed is approximately the same under different illumination and distances. This shows that when appropriate conditions are met during the reading process, stable reading speeds can be obtained. The results only account for the moment in which the camera is being pointed at the code, assuming the camera and the application are on.

B. NFC

In similarity with the QR Codes, the reading speeds that were achieved while performing the reading of NFC tags were stable. When reading the tags using the described materials, similar average reading times were obtained, with the exception of the glass test. In this test, due to the properties of the barrier, the mobile device could not read the code. Fig. 6 presents the average results of these readings.

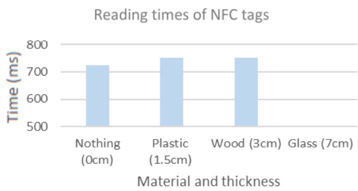


Fig. 6. Reading times of the NFC tags

It is possible to observe that the bars shown in the chart are almost at the same level, except the last one that does not show any value, considering that the reading failed.

C. Beacons

The distance calculation method used by beacons has shown several limitations in previous work [24, 25]. The results of the distance tests had the same outcome, with the distance estimations being inaccurate. As a result, the approach presented relies on the monitoring (proximity detection) method. This method detects entering and exiting a defined region and, given the relevance, the test results corresponding to this method are presented in more detail. The results showed accurate zone detections, with several sleeping times and beacon advertising interval combinations: the maximum time it should take to detect an entrance/exit is the sleeping time + scanning time (orange line), which was mostly confirmed (the theory only failed in ≈5.6% of situations in the entering detection test and ≈11.1% of situations in the exit detection test). Scanning times inferior to 1s were not reliable. The scanning time should be greater than the beacon's advertising interval to assure reliability.

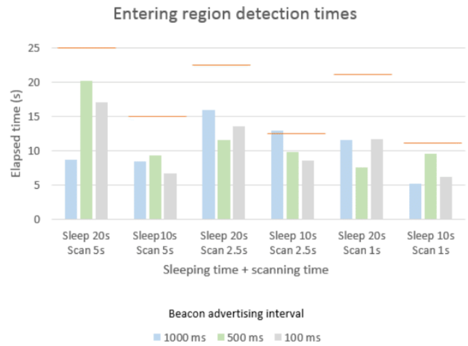


Fig. 7. Entering region detection times

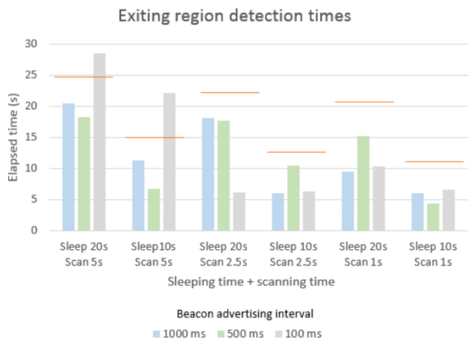


Fig. 8. Exiting region detection times

VI. CONCLUSIONS

These technologies offer different ranges of advantages to both the operators and passengers, providing services with different costs, interaction needs and visual customization levels. If the operators want to provide their users a service that requires the least interaction possible, BLE and beacons should be chosen, at the expense of a higher maintenance and investment cost. On the other hand, if a system with the lowest infrastructure costs is to be implemented, then QR Codes or NFC should be chosen, with QR Codes having the clear advantage of having a lower cost and NFC having a more pleasant interaction with the user. This comparison is one of the major contributions of this paper and it can be used to support the decision of which technologies to use in similar contexts.

Figure C.5: Fifth page of paper

The results allowed to conclude that QR Codes and NFC may easily be applied to mobile ticketing solutions in public transportation, especially considering the good reading speeds, robustness and level of maturity, in which a trade-off between cost and ease of use should be considered. However, QR Codes carry more restraining factors than NFC tags due to the conditions present in transportation stations. In some cases, it might be dark in the station, and as such methods to address these conditions are required. One solution for this is the usage of flash present in the smartphone for dark environments, or by producing larger codes. Finally, as for NFC, from the tests that were performed, it can be seen that this technology works well with the expected materials being found in stations, like plastic.

As for the use of beacons (and BLE) it is possible to determine that it is feasible but can be enhanced and made more reliable as the technology improves. Currently, beacons could not be used reliably if an estimated distance is required, but may be used when knowing if a user is nearby is enough (given the detection time results).

The proposed and analyzed approaches make use of the considered technologies and have the possibility to revolutionize the ticketing infrastructure, as it exists today, providing a contribution for the public transportation area. These approaches allow users to gain more control over their trips and use a more customized and user-friendly process while allowing operators to avoid installing and maintaining complex and expensive infrastructures and to collect more information.

Future work consists on implementing prototypes of the approaches and later test them with users in a real context.

ACKNOWLEDGEMENTS

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Figure C.6: Sixth page of paper